Effects of Flow Fluctuation and Redd Dewatering on Salmonid Embryo Development and Fry Quality

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EFFECTS OF FLOW FLUCTUATION AND REDD DEWATERING ON SALMONID EMBRYO DEVELOPMENT AND FRY QUALITY

bY

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Submitted to

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ABSTRACT

During the fall and winter 1979-1980 tests were conducted in a section of the Middle Snake River within Hells Canyon to determine the effects of hydroelectric power peaking on fall chinook salmon (*Onchorhychus tshawytscha*) embryo incubation and fry quality. Additional simulated peaking tests were conducted at the Hayden Creek research station using artificial stream channels. Steelhead trout (*Salmo gairdneri*) and chinook salmon egg dewatering tolerance tests were conducted at the Hayden Creek stating using 16 independent flow controllable chambers. In Hells Canyon, no definitive relationship was found between embryo survival and the incidence of flow fluctuations and periodic redd exposure. However, the highest embryo survivals occurred in areas dewatered the least. There was extensive sediment intrusion into the artificial fall chinook redds within Hells Canyon. In laboratory tests, no significant difference ($P \geq 0.05$) in survival were found between embryos periodically dewatered (11-12 hr/day) and those continually watered, although alevins from the channel which was dewatered were significantly longer ($P < 0.0037$) and heavier ($P > 0.0391$) than alevins from the control. This resulted from elevated temperatures in the dewatered riffles. Steelhead trout and chinook salmon embryos were tolerant to 1-5 weeks of continuous dewatering with no significant effects on survival to hatching (provided embryos remained moist), alevin quality, growth rates, or latent fry quality. Alevin dewatering tolerance limits are estimated to be less than 10 hours. Gravel moisture within dewatered artificial redd remained relatively constant throughout 1-5 week dewatering periods. Gravel moisture levels of approximately 4% or greater appear to be sufficient to allow salmonid embryos to withstand periods of dewatering, provided temperatures

remain within embryo incubation tolerances. The most pronounced effect of long term embryo dewatering in the laboratory tests was accelerated development with hatching modes as many as 14 days earlier than embryos incubated in water. Dewatered embryo development may be delayed during periods of cold temperatures. Regardless of incubation condition tested, or duration, fry reared 57-60 days exhibited no significant differences in length or weight.

INTRODUCTION

To efficiently utilize water for power production, most hydroelectric projects operate on a demand basis. This generally results in some level of sustained power production throughout the day (base load) with a sharp increase during one or more shorter periods of time (peak load). The highest demands for power generally occur during weekdays during daylight hours while the lowest demands are associated with the nighttime and during weekends. To provide peak loading, large amounts of water must be released in a relatively short period of time. These rapid water fluctuations could adversely affect salmonid spawning and egg incubation success.

Of particular concern are the impacts of power peaking on Snake River fall chinook salmon (Onchorhynchus tshawytscha) whose numbers have decreased from 30,049 in 1962 to 1756 in 1977 at Ice Harbor Dam. Hydroelectric development has reduced the useable fall chinook spawning area in the Snake River from 630 miles (1013 km) to an 88 mile (141 km) section within Hells Canyon (Anon 1978). Flow in this reach is regulated by Hells Canyon Dam. During the fall and winter, daily fluctuations in flows from 10,000 to 29,000 cubic feet per second (cfs) (282 to 821 m^3/s) and higher are common. Such fluctuations can result in stage differences of 5 ft (1.5 m) or more. Fall chinook salmon may spawn in areas which are subsequently dewatered during non-peaking periods. Alternating watered and dewatered conditions may continue through- out the entire incubation period.

The seriousness of this problem has already been shown on the Columbia River below Priest Rapids Dam where in 1976 an estimated 833,897 swim-up fry were killed when flows were reduced below fall chinook redds (Bauersfield 1978). Studies are continuing on this section of river to ascertain the overall effects of flow fluctuation on fall chinook embryo incubation and fry survival (Tom Welch personal communication, University of Idaho, 1980).

The potential effects of flow fluctuations on embryo survival and resulting fry quality include desiccation of embryos, increased susceptibility of embryos to freezing conditions, sedimention of redds, and lowered intragravel dissolved oxygen levels.

Our study was designed to determine if flow fluctuations adversely affect chinook salmon embryo development and fry quality. In our evaluation we tested the ability of salmonid embryos to survive varying periods of dewatering followed by flow restoration. We also experimentally examined the tolerance limits of salmonid embryos to varying periods of complete dewatering and monitored resulting fry for quality differences.

DESCRIPTION OF STUDY AREA AND TEST FACILITIES

Field Study

We conducted our field tests in a section of the middle Snake River which flows through Hells Canyon, the deepest gorge in North America. This reach of the river extends from Hells Canyon Dam (river mile 243 (river kilometer 399)) to the towns of Lewiston and Clarkston RM 140; (RK 225), a distance of 108 miles (174 km).

The flow of the river is regulated by Hells Canyon Dam with daily flows averaging 22,460 cfs (636.1 m^3/s) since 1965. The maximum and minimum discharge recorded was 75,800 cfs (2150 m^3/s in April of 1971, and 4950 cfs (140 m^3/s) in May of 1968 respectively. The maximum flow recorded during our study (14 November 1979 and 25 February 1980) was 30,450 cfs (862.3 m^3/s) on 29 January 1980 while the minimum was 9200 cfs (260.5 m^3/s on 22 December. Daily flow fluctuations as a result of peaking operations occurred throughout our study period, often resulting in stage changes of up to 1.5 m (5.0 ft) (Figure 1).

We selected four study sites within a 43.4 km (27 mile) section of the river extending from RM 196 (RK 315) to RM 223 (RK 358) (Figure 2). Study areas were selected on the basis of suitability of water depths, velocities and substrates for fall chinook salmon spawning, historical spawning documentation., susceptibility of the areas to flow fluctuations, and accessibility and proximity to other sites. Areas selected offered a range of depths and velocities with an expected dewatering frequency from often to never.

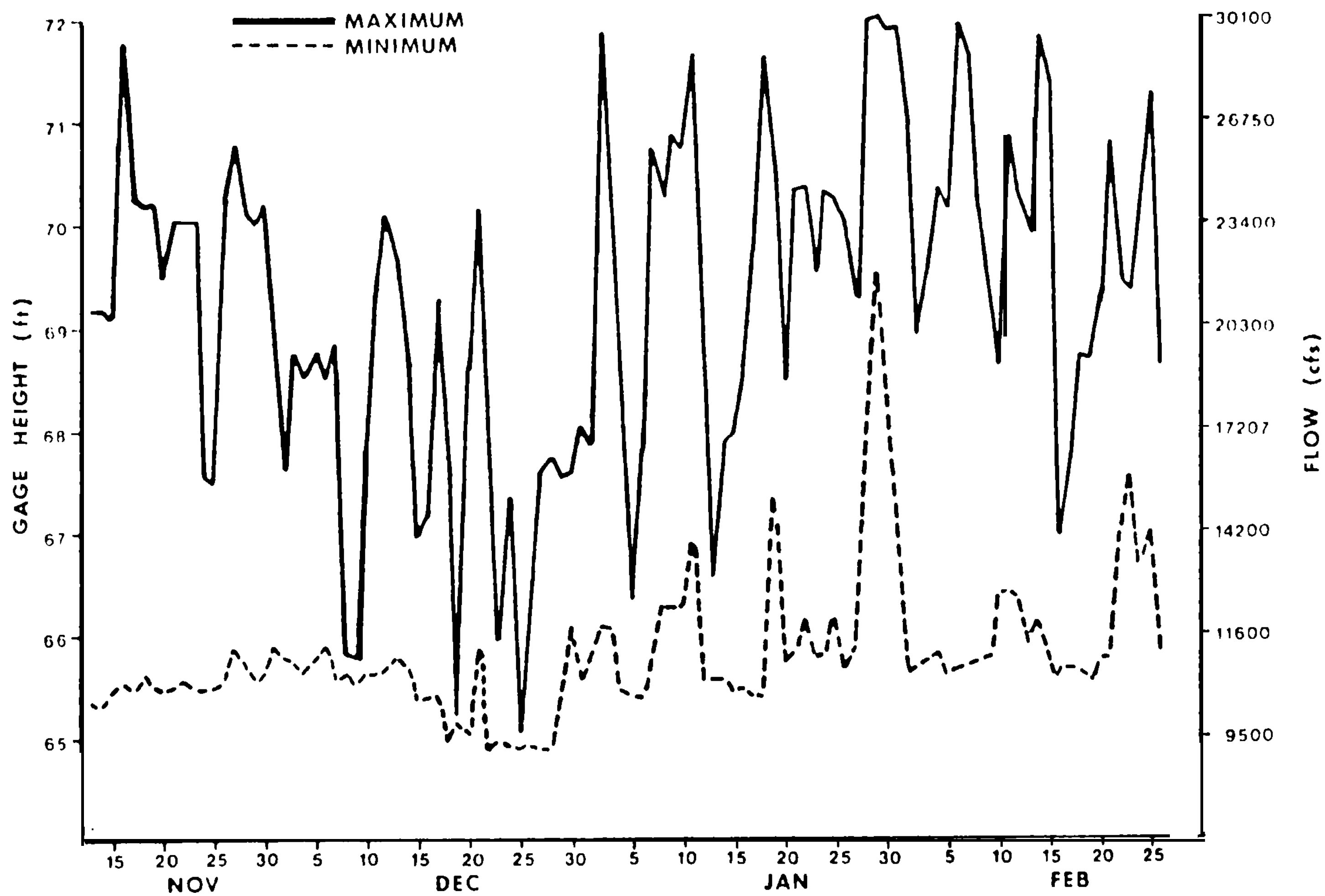


FIGURE 1 Maximum and Minimum Gage Height and Associated Flow of the Snake River Below Hells Canyon Dam During Fall Chinook Egg Incubation Study, winter 1979-80.

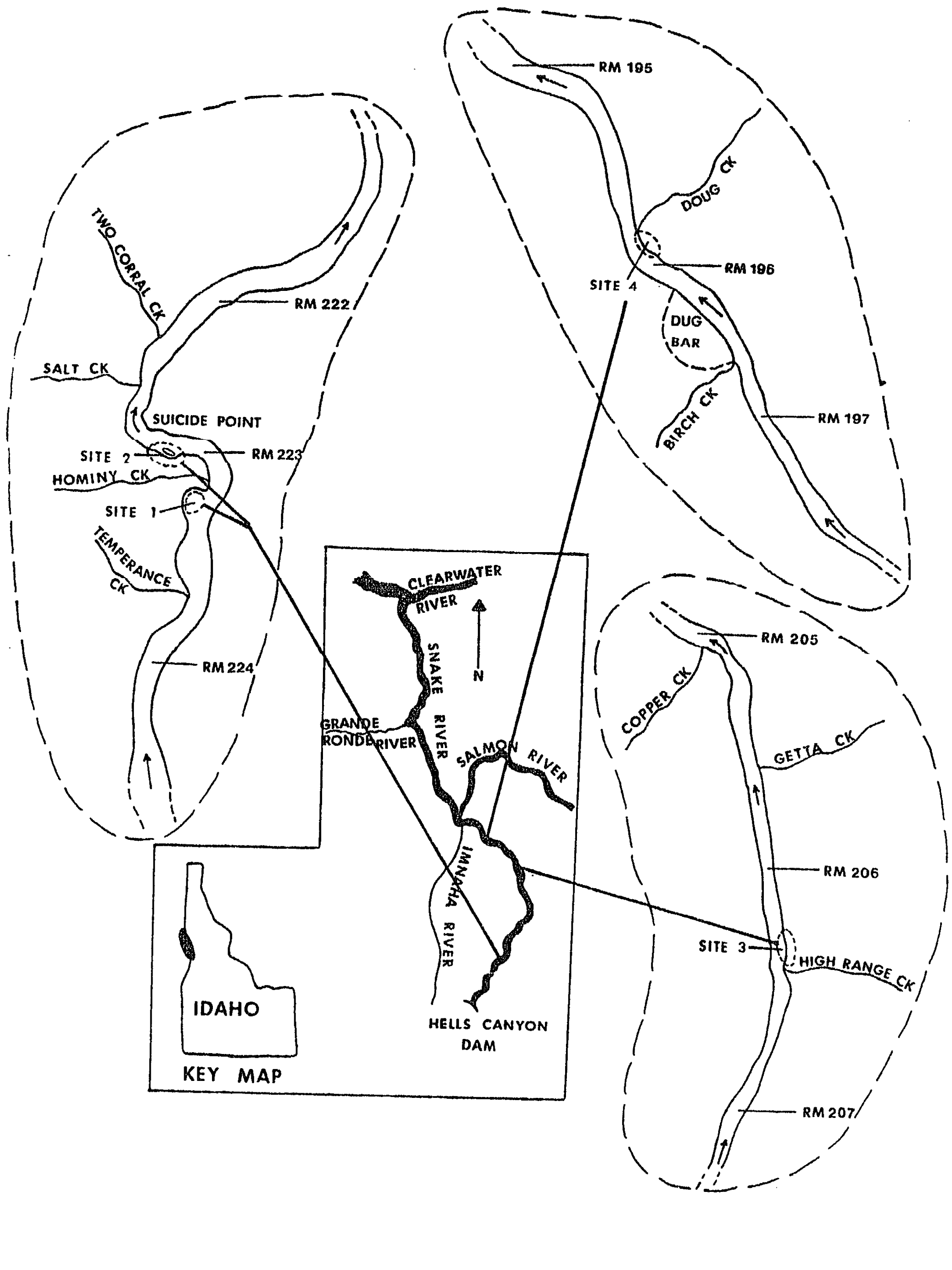


FIGURE 2. Location of the Four Snake River Study Sites Used To Evaluate Effects of Fluctuating Flows on Incubation Success of Fall Chinook Salmon, November 1979 - February 1980.

Site 1 was located within RM 223 (RK 358) approximately 0.48 km (0.3 mile) upriver from Suicide Point. The area consisted of a small gravel bar (45.7m (150 feet) long x 30 m (100 ft) wide) arising about 12.2 m (40 ft) out from the left side (Oregon) of the river. Hominy Creek enters the Snake River a short distance downriver from this site (Figure 2).

Site 2 was located within RM 223 (RK 358) approximately 0.16 km (0.1 mile) upstream from Suicide Point and 0.32 km (0.2 mile) downriver from Site 1 (Figure 2). The study area was located on the Oregon side of the river where a large gravel bar bordered its perimeter.

Site 3 was located within RM 206 (RK 331) 1.4 km (0.85 mile) upriver from Copper Creek (Figure 2). The study area was on the Idaho side of the river directly below High Range rapids, and consisted of a large gravel deposit extending well out into the river.

Site 4 was located within RM 196 (RK 315) on the Idaho side of the river and encompassed a large gravel covered area across from Dug Bar.

Laboratory Study

We conducted simulated peaking tests in four experimental channels located at the Idaho Department of Fish and Game's Hayden Creek Research Station near Lemhi, Idaho (Figure 3). Each channel measured 20.6 m long x 1.2 m wide x 0.6 m deep (68 x 4 x 2 ft) and contained two riffle and three pool areas (Figure 4). Riffle substrate was comprised primarily of material ranging from 12.7 to 76.2 mm (0.5 to 3.0 inch) in diameter. Sediment levels increased from riffles l-4 with material $\leq$4.6mm (0.18 inch) in diameter averaging 0.93% in riffle 1; 15.5% in riffle 2; 22.7% in riffle 3; and 32.9% in riffle 4.

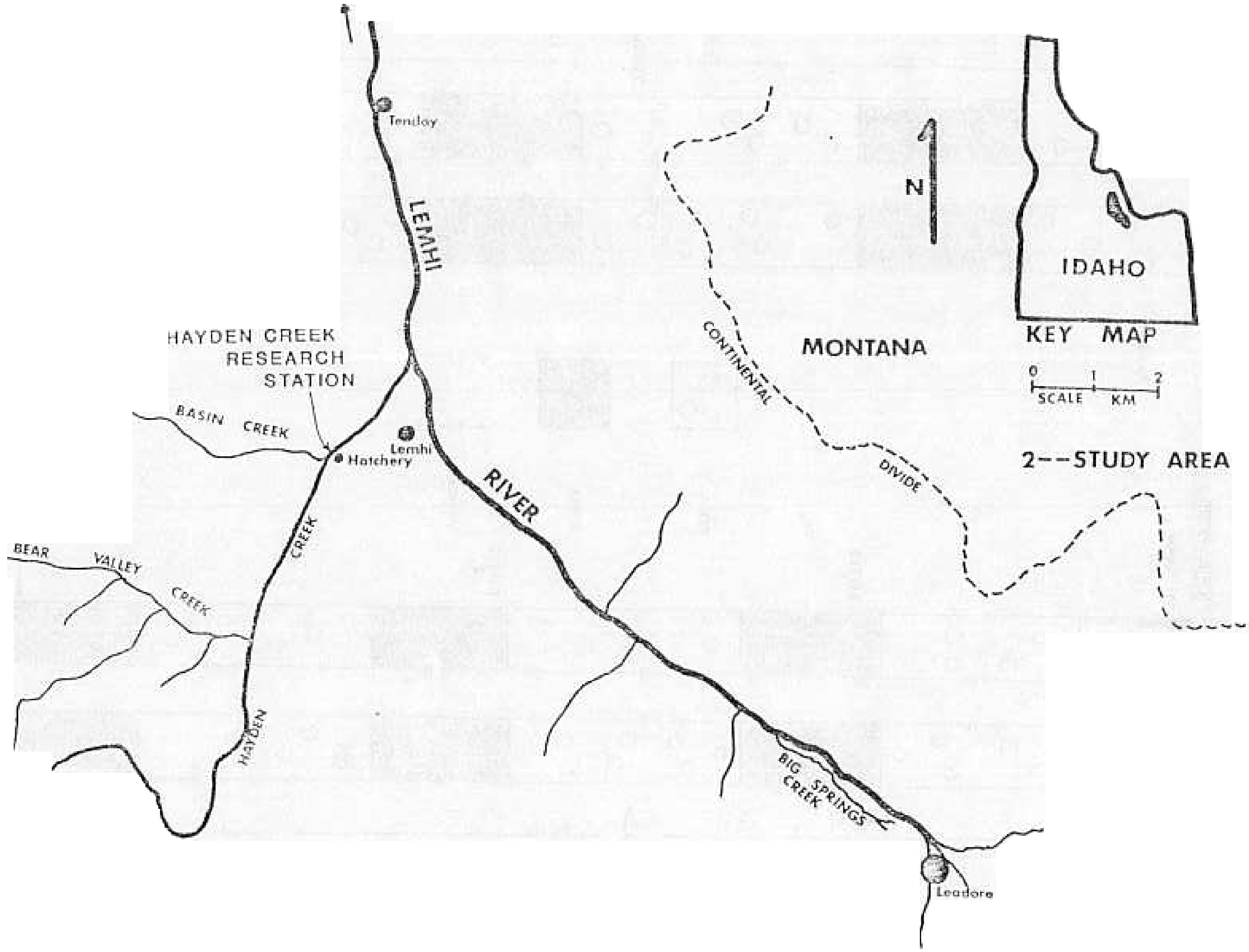


FIGURE 3. Map Showing the Location of The Hayden Creek Research Station, near Lemhi, Idaho, Where Simulated Peaking Tests Were Conducted, Fall 1979-80.

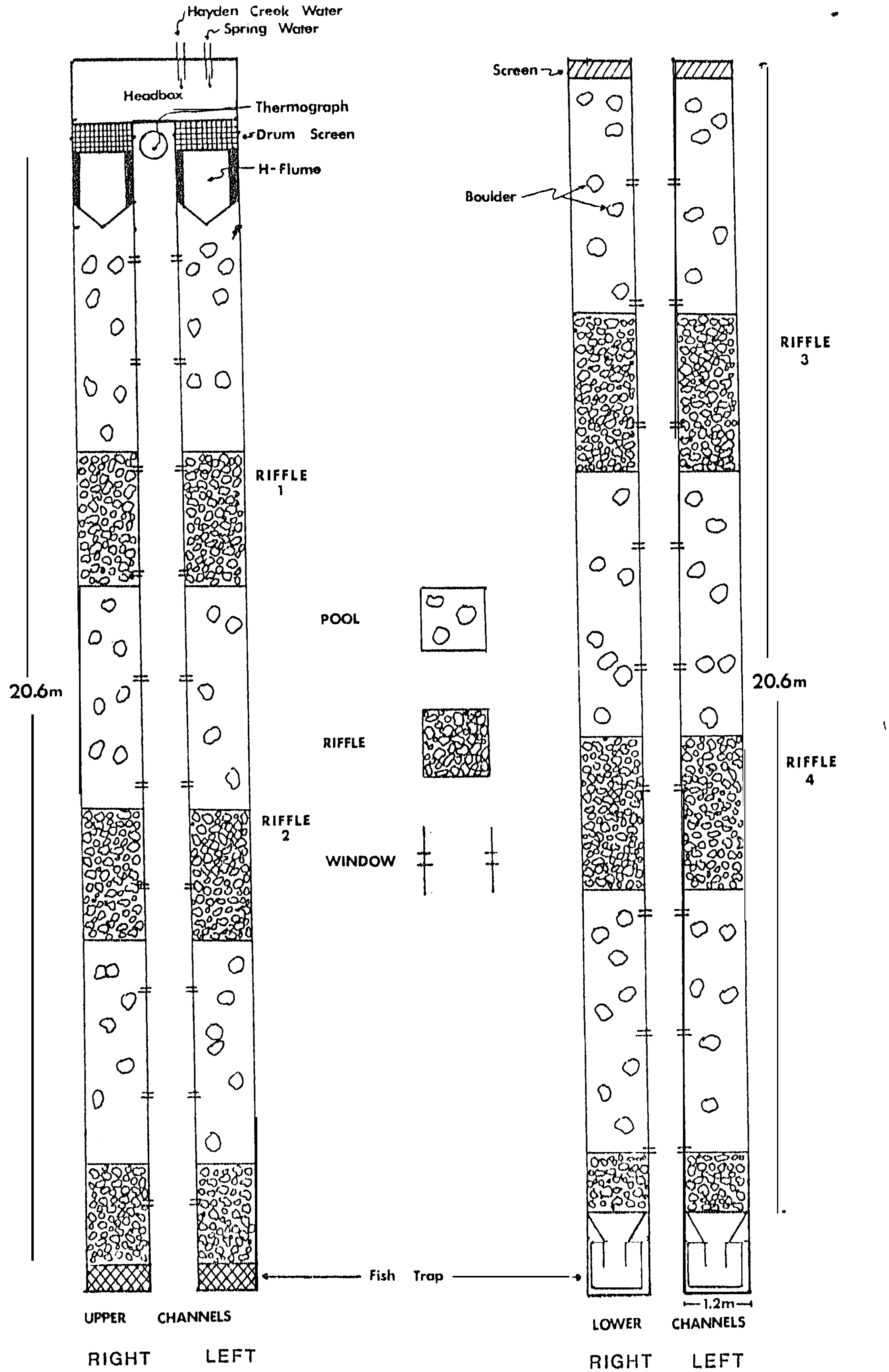


FIGURE 4. Schematic Diagram of The Four Artificial Stream Channels Located At The Hayden Creek Research Station Near Lemhi, Idaho, Where Simulated Peaking Tests Were Conducted, Fall 1979-80.

Water was supplied to the channels directly from Hayden Creek or from a constant temperature spring (12 C). Water flow to the channels was controlled by two headgates and flow in each channel could be regulated. Two 0.46 m (1.5 ft) H-flumes located at the head of each channel measured discharge.

Embryo dewatering tolerance limit tests were conducted in two 1.2 m wide x 2.4 m (4.0 x 8.0 ft) long channels each with eight 1.2 m long x 0.3 m wide x 0.3 m (4.0x 1.0 x 1.0 ft) deep independent flow controllable chambers. The channels were installed outside and were plumbed with Hayden Creek water. Each chamber was filled with gravel consisting predominantly of material 6.4 to 76.2 mm (0.25 to 3.0 inch) in diameter. Fine sediment (< 6.4 m) was added in known percentages and particle sizes.

Fry rearing tests were conducted in four 4.6 m long x 0.3 m wide (16.0 x 1.0 ft) troughs each subdivided into eight 0.6 m long (2.0 ft) compartments separated by screen barriers.

METHODS

FLOW FLUCTUATION TESTS

Field Study

To monitor flow fluctuations at each Snake River study site, we installed a 2.4 m (8 ft) x 0.24 m (0.8 ft) diameter stilling well, housing a Steven's F-l electric drive 16 day water level recorder, and a staff gage (Figure 5, 6, 7, 8 and 9). Air, water and intragravel temperatures were monitored at select locations using a Peabody-Ryan 90-day submersible thermograph and/or a Partlow 30 day 2 pen thermograph.

Fertilized green fall chinook eggs from Bonneville Hatchery, Oregon, were transported to Pittsburg Landing on 14 November 1979. Embryos were counted into gravel filled Whitlock-Vibert boxes (W-V boxes) with 100 embryos/box and stored overnight in water filled coolers. A 3 ml water filled vial was placed in each W-V box as an indicator of intragravel freezing. All embryos were planted on 15 November by 1400 hours (27 hours after fertilization). Ten artificial redd sites were selected at each study area with sites including areas which would be dewatered frequently, occasionally and never (controls). Egg boxes were buried at a depth of 25.4 to 30.4 cm (10 to 12 inches). A Mark VI standpipe (Terhune 1958) was installed immediately anterior to and at the same level as the embryos to allow measurements of intragravel dissolved oxygen and temperature. A 20.3 cm (8 inch) diarneter substrate core sample (McNeil and Ahnell, 1964) was taken directly downstream from each artificial redd. Samples were volumetrically analyzex using a series of nine sieves ranging in size from 76.2 to 0.42 mm (3.0 to 0.016 inch).

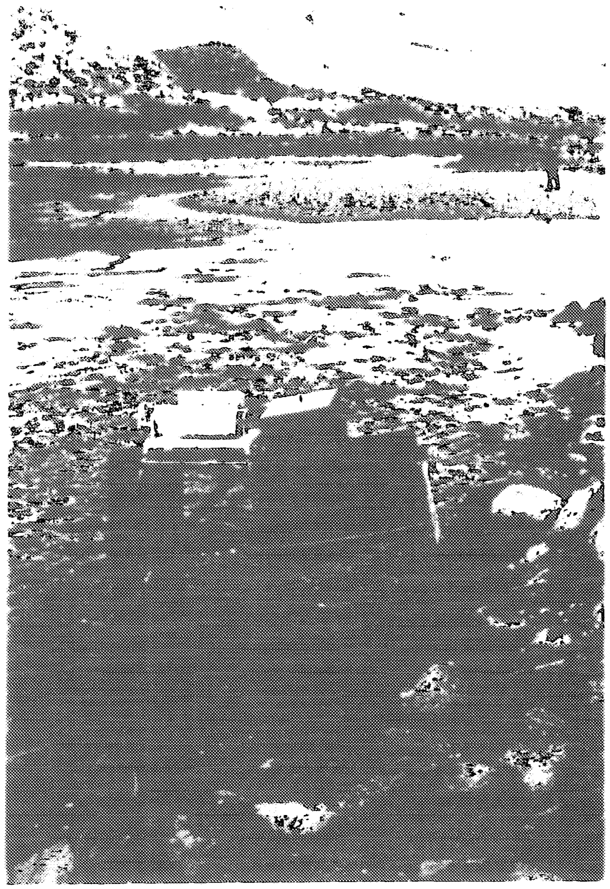


FIGURE 5. Stilling Well and Water Level Recorder Located At Site 4 (Dug Bar) Utilized to Monitor Flow Fluctuations During Fall Chinook Embryo Incubation Tests, Snake River, Winter 1979-80.

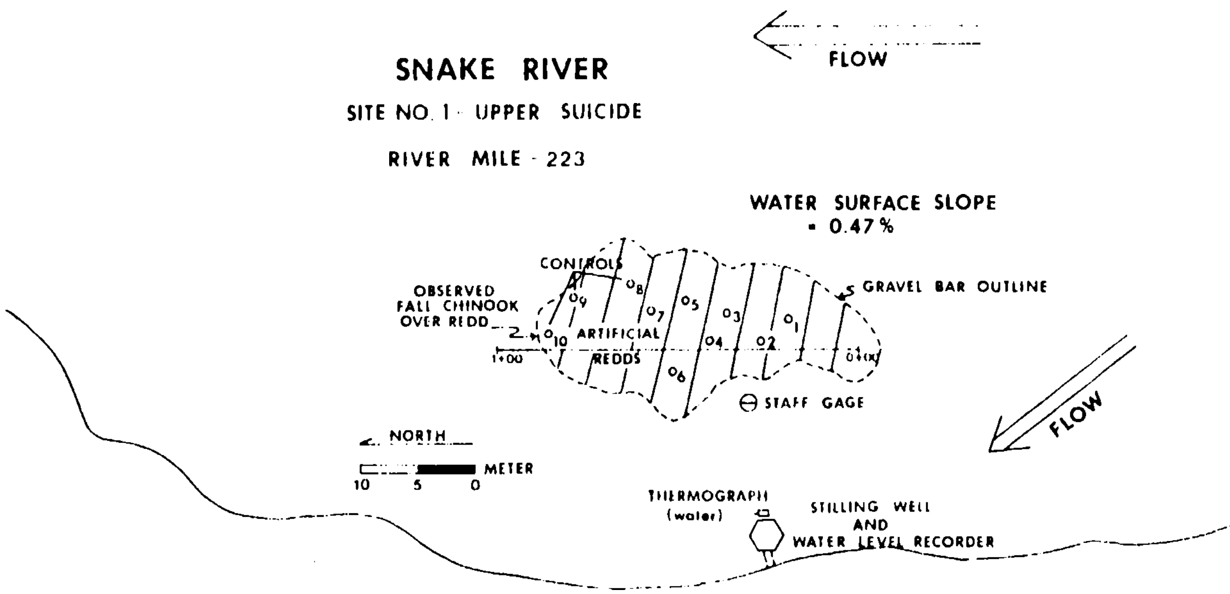


FIGURE 6. Map of Study Site No. 1, Located on The Snake River at River Mile 223 U
For Fall Chinook Embryo Incubation Study, Winter 1979-80.

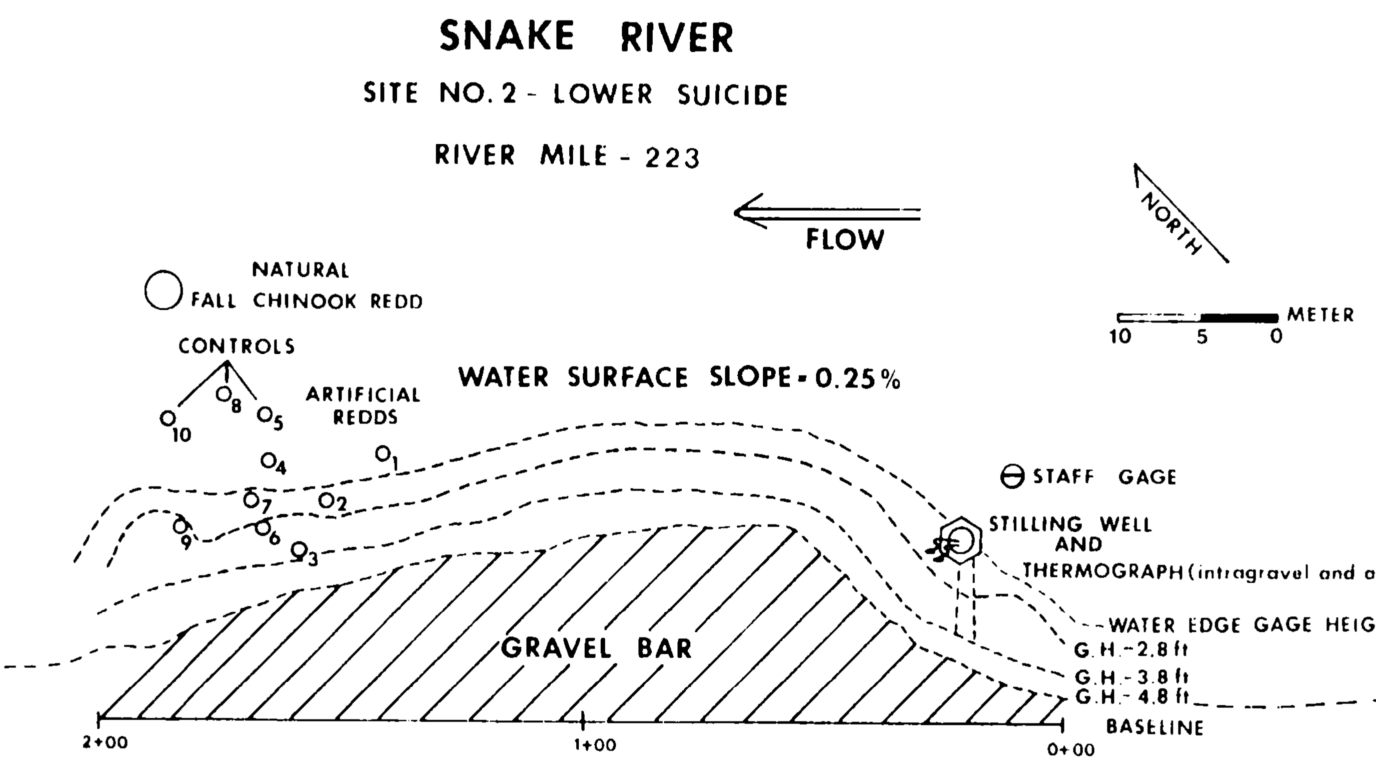


FIGURE 7. Map of Study Site No. 2, Located On The Snake River at River Mile 223 U
For Fall Chinook Embryo Incubation Study, Winter 1979-80.

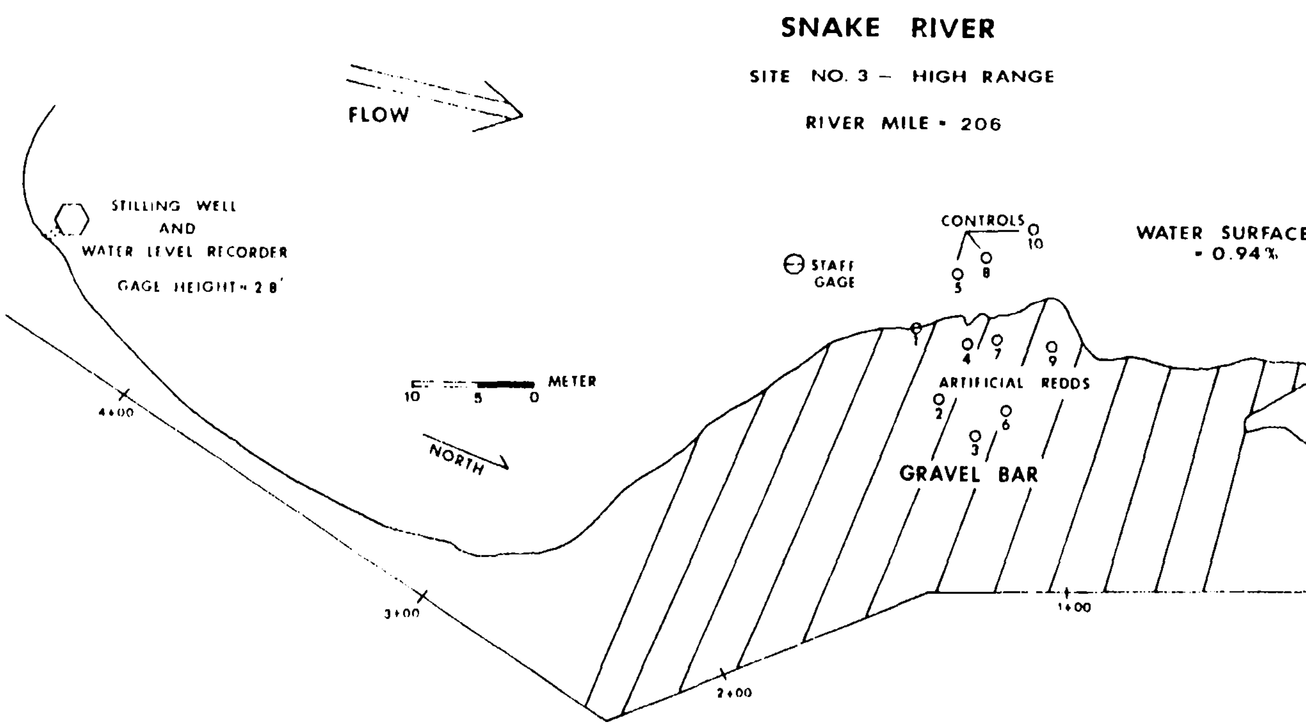


FIGURE 8. Map of Study Site No. 3, Located on The Snake River at River Mile 206 For Fall Chinook Embryo Incubation Study, Winter 1979-80.

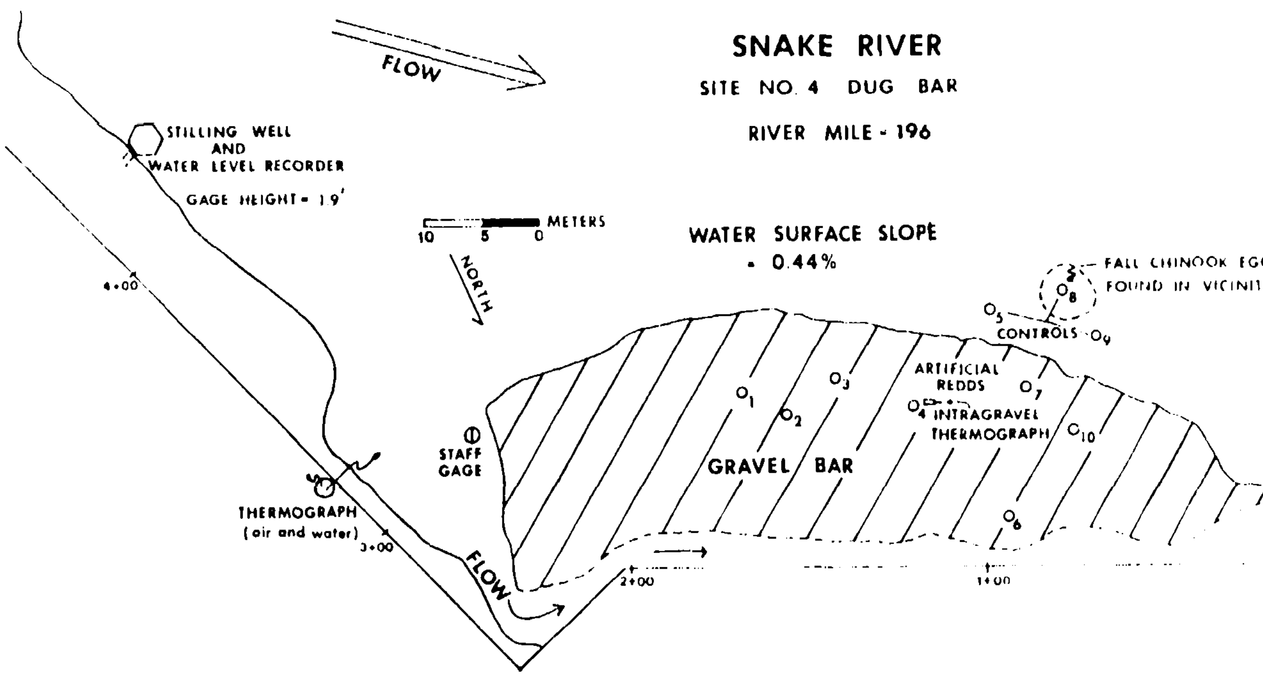


FIGURE 9. Map of Study Site No. 4, Located on The Snake River at River Mile 196 U
For Fall Chinook Embryo Incubation Study, Winter 1979-80.

Water depth, velocity (0.6 depth), and dissolved oxygen were measured at each redd at several discharges. Velocities were measured with a Marsh-McBirney electronic current meter while dissolved oxygens were measured with a Yellow Springs Instrument (YSI) 54-ARC oxygen meter. Water depths were related to staff gage and water level recordings. This relationship enabled us to compute the amount of time embryos were dewatered. We assumed this would occur when the water level was reduced 15.2 cm (6 inch) below the substrate surface of each redd. At one site (Site 2) we mapped the water edge at 0.30 m (1.0 ft) gage height intervals to determine when surface flow ceased over the redds.

Cumulative dewatering time for each redd was calculated by relating the staff gage height readings at each site to the hourly gage height readings at Hells Canyon Dam (station # 13290450) (Figure 10). Once the gage height reading at the dam corresponding to the site reading at which the embryos become dewatered was determined, the total hours of dewatering for each redd was computed by summing the hours the gage height reading was below this value. The longest continuous period of dewatering was similarly determined.

Water surface slope was measured at each site using an Abney level and philly rod. Study areas were mapped using a transit and philly rod noting the locations of the artifical redds, thermographs and stilling wells.

On 6 February 1930, we recovered one W-V box from redd number 3 at Site 4. Embryos appeared to be in good condition and were just beginning to hatch. We scheduled complete survival assessment for the following week, 15 February, but due to mechanical problems embryos were not recovered until 18 March. Because of this delay, embryos and fry were in many instances,

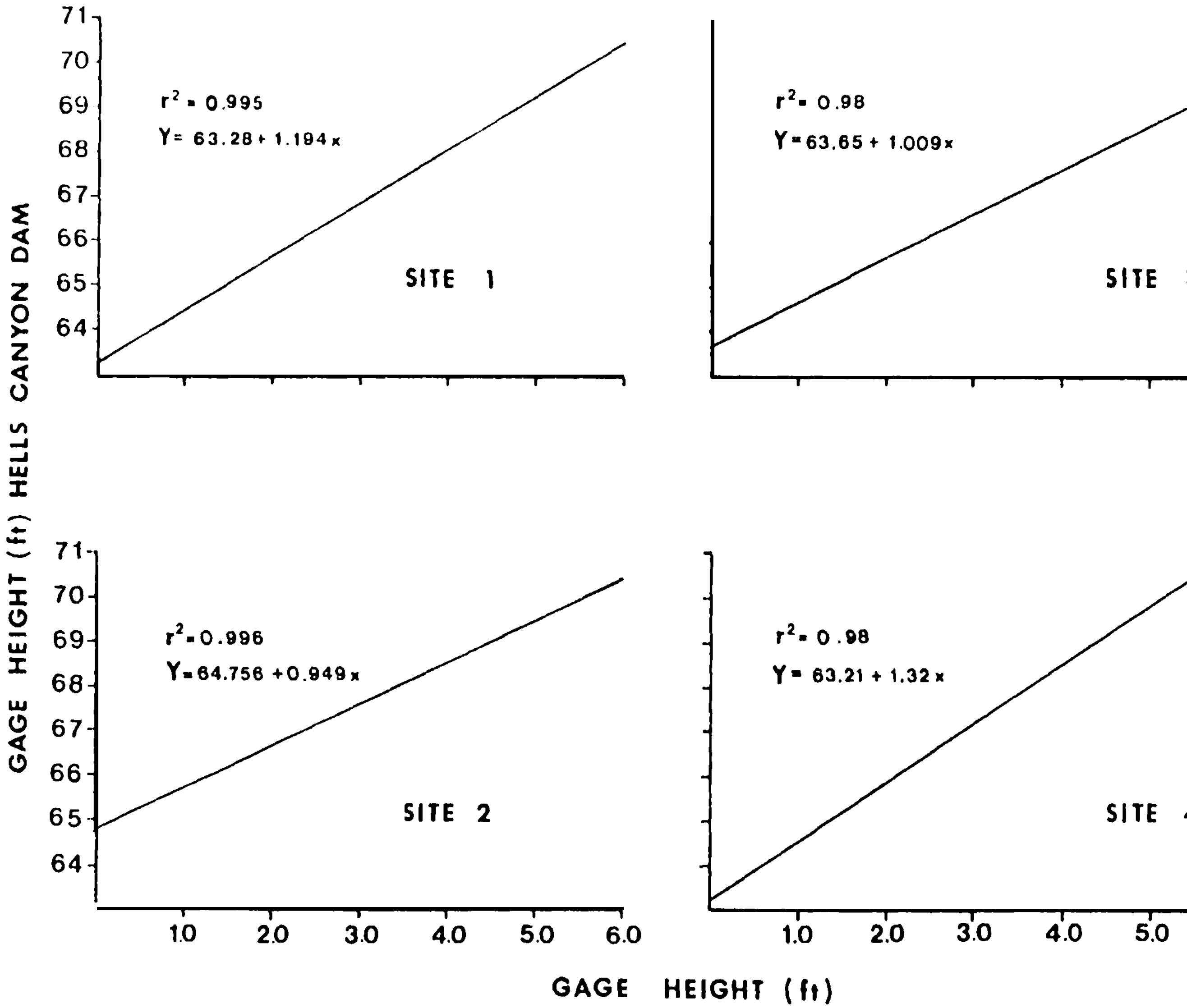


FIGURE 10. Gage Height Relationship Between Hells Canyon Dam Gaging Station and t
Sites Located on the Snake River, Winter 1979-80.

badly decomposed. Immersion in formalin hardened the remnants, and we carefully analyzed the boxes by counting the number of embryos and yolk sacs as well as live alevins present in each box.

Laboratory Tests

We conducted peaking tests in the Hayden Creek channel using fertilized green eggs of spring and fall chinook salmon. Spring chinook embryos were obtained 5 September 1979 from the Washington Department of Fisheries Cowlitz Hatchery located near Toledo, Washington; fall chinook embryos were procured 6 December 1979 from the Oregon Department of Fish and Wildlife Bonneville Hatchery. Embryo planting procedures and flow regulations apply to both tests with exceptions noted.

In each of the four riffles we constructed three artifical redds and planted gravel filled W-V boxes with 100 embryos/box (Figure 11). A 3 ml waterfilled vial was placed in each box as an indicator of intragravel freezing. All boxes were buried approximately 20.3 cm (8.0 inch) deep. A Mark VI standpipe was centrally positioned within each redd at the level of the embryos to enable measurements of intragravel dissolved oxygen and water temperature (Figure 11). Water and intragravel temperatures were monitored continuously using recording thermographs.

Water flows for the spring chinook test were regulated to provide 4.5 to 9 cm (1.7 to 3.5 inch) of water over all riffle areas during peaking hours (1021 &/min (0.6 cfs)). Because of a water shortage, peaking flows during the fall chinook tests were less (171.8 ℓ/min (0.10 cfs)). Water depths and velocities were measured over each redd using a top setting rod and a Marsh-McBirney electronic current meter. Mean water velocities in each channel were determined using time of travel techniques employing fluorescent dye.

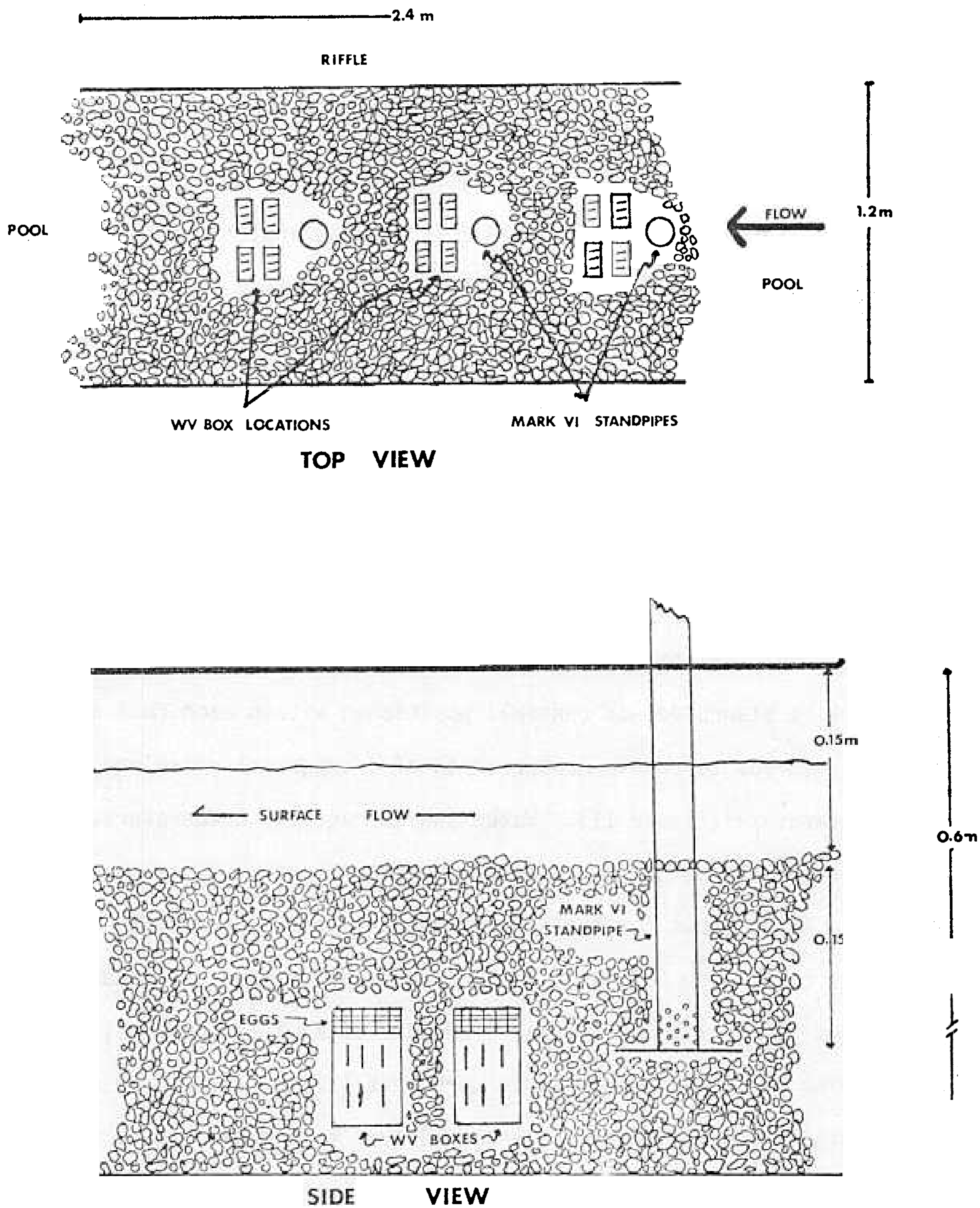


FIGURE 11. Top and Side View of Artificial Redds Illustrating Relative Positions of Whitlock-Vibert Boxes and Mark VI Standpipes Used To Evaluate Effects of Water Fluctuation on Incubation of Chinook Salmon Embryos, Hayden Creek Artificial Channels, 1979.

We operated the peaking channel (test) on a 12 hour on/off schedule with embryos watered from 0800 to 2000 hr and dewatered from 2000 to 0800 hr (Figure 12). Flow in the nonpeaking channel (control) remained relatively constant throughout the incubation period.

During the spring chinook tests embryos were dewatered throughout the weekend resulting in a total period of constant dewatering of 60 hrs. We initiated the peaking regime on 7 September for spring chinook and 9 January for fall chinook. Because of potential intragravel freezing during the fall chinook tests, we covered the riffle areas during periods of dewatering with 5.1 cm (2.0 inch) thick plastic lined insulation.

When embryos placed in Heath stack incubators began to hatch we discontinued tests and maintained flows in both channels until hatching was complete. We assessed survival in the redds by recovering all W-V boxes and counting the number of dead embryos. A representative sample of the alevins from each W-V box was preserved in 10% formalin for analysis of fry quality (total length 0.5 mm, and weight 0.1 mg).

Random samples of 300 alevins from each channel were transferred to separate 30 m (10 ft) long troughs and reared for 2 months to allow comparisons of growth, final length and weight.

Following survival assessment we collected a substrate sample from each redd using a 20.3 cm (8.0 inch) diameter core sampler (McNeil and Ahnell 1964). Samples were volumetrically analyzed as previously discribed.

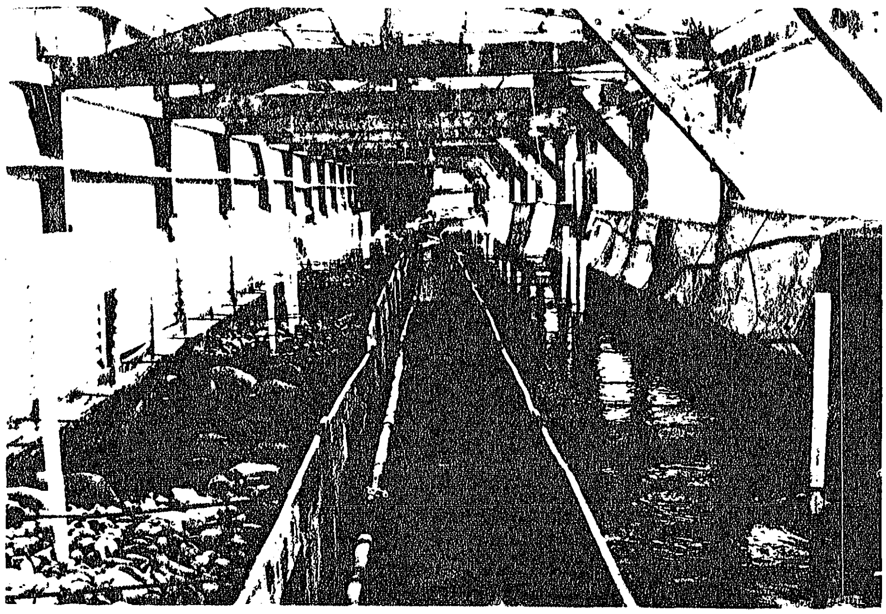
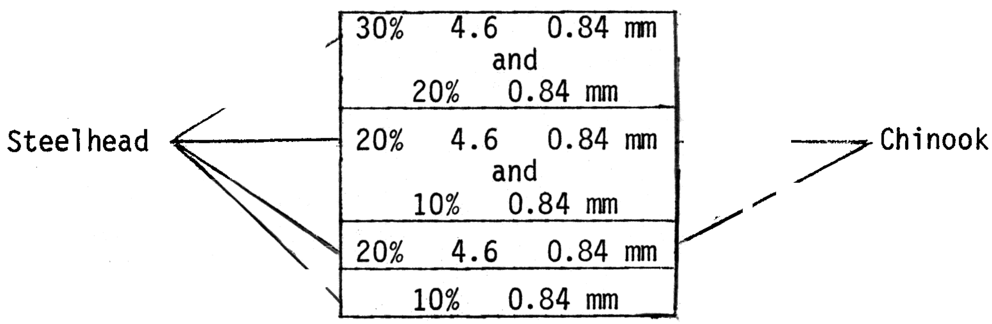


FIGURE 12. Hayden Creek Experimental Channels Used to Determine The Effects of Flow Fluctuation on Chinook Salmon Embryo Incubation. Test Channel (left) was Dewatered on a 12 hr. On/Off Schedule. Control Channel (right) Flow was Constant During Test. Mark VI Standpipes Indicate Egg Location, Fall 1979.

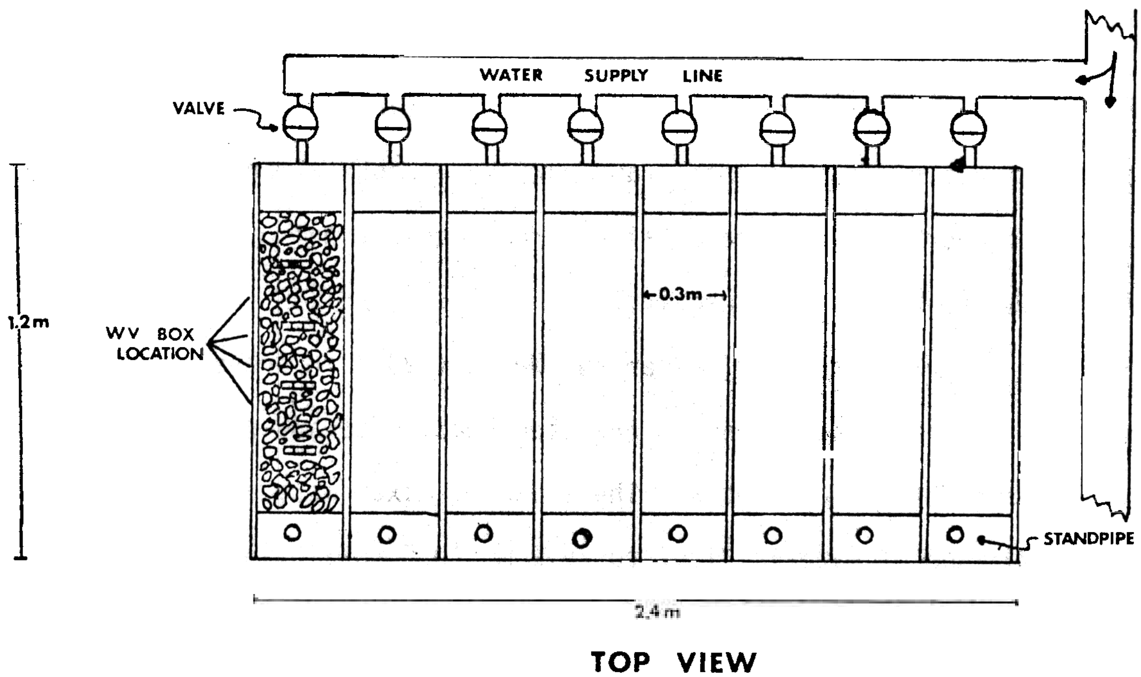
EMBRYO DEWATERING TOLERANCE TESTS

Dewatering tolerance tests were conducted using fertilized green steelhead trout (Salmo gairdneri) and spring chinook salmon eggs. Steelhead and chinook embryos were obtained from Dworshak National Fish Hatchery and Cowlitz Hatcher, respectively

Based on prior studies (Reiser and White (1981 in press) we utilized four sediment-substrate mixes for the steelhead tests and reduced this to two mixes for the chinook tests The sediment mixes were added to substrate comprised of materia 12.7 to 76.2 mm (0.5 to 3.0 inch) in diameter The mixes we tested were



In both tests, four gravel filled W-V boxes, each containing 100 fertilized eggs in the upper compartment were equidistantly spaced within each chamber and covered with approximately 15.2 cm (6.0 inch) of the sediment mix (Figure 13). A water filled vial was placed in each W-V box during the chinook tests as an indicator of intragravel freezing. Pacific Transducer remote bulb thermometers were placed at the level of the embryos in four dewatered chambers. Temperatures were recorded three times daily (0800, 1200, 1600 hrs) Intragravel temperatures were continually recorded during the steelhead tests using a Parlow thermograph Air and water temperatures were monitored using Taylor and Weathermeasure thermographs.



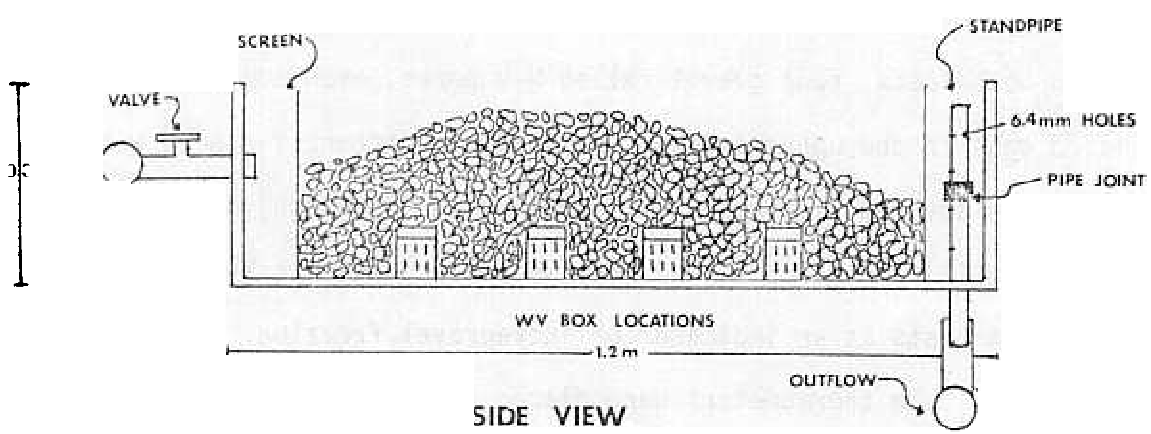


FIGURE 13 Top and Side View of Experimental Chambers Used in the Embryo Dewatering Tolerance Tests, Showing Position of The Whitlock-Vibert Boxes, Hayden Creek Research Station, Lemhi, Idaho, 1979.

We used only one set of experimental channels for the steelhead tests. We used two sets of channels in chinook tests and replicated the same sediment mixture twice in each channel. A roof protected one set of chambers from rain and snow.

When experiments were initiated flows were adjusted in all chambers to provide approximately 2.5 cm (1.0 inch) of water passing over the substrate. After 3 days, the flow in one of two adjacent chambers containing similar sediment mixes was reduced below the level of the embryos. A small inflow was maintained in these chambers to simulate groundwater. Embryo survival was assessed at weekly intervals in both the watered and dewatered chambers. Survival analysis included recovering one W-V box/chamber/sampling period, counting the number of dead embryos and placing the viable embryos in separate Heath stack trays to monitor ultimate hatching success.

During each sampling period a sample of the gravel-sediment mix surrounding the eggs was collected from the dewatered chambers, placed in soil tins and analyzed for moisture content. This entailed weighing each sample, drying the samples in a forced air oven at 110 C for 24 hours and reweighing. The difference in weight was due to the moisture content of the mix, which was expressed on a percentage basis.

When all eggs had hatched, equal samples of fry were transferred to compartmentalized rearing troughs. A programmed feeding schedule was used throughout the rearing tests. The amount of feed/week/compartment was calculated by:

grams of feed = 0.035 x ave. body wt/fish x no. of fish x 7 days

Where: 0.035 is the percent of body weight to feed/day (Deuel et al. 1952).

We reared steelhead using both Hayden Creek and spring water, but used only spring water for the chinook tests. All fry were inventoried and weighed on a weekly basis throughout the rearing period, which extended from 19 August to 18 October 1979 for steelhead and 15 January to 12 March 1980 for chinook. After the final inventory, samples of fry were preserved in 10% formalin to allow further comparison of length and weight.

RESULTS

FLOW FLUCTUATION TESTS

Field Study

Evidence of natural spawning was observed at three of our four embryo planting sites. An adult fall chinook was observed over one of the control redds at site 1 while natural redds were observed near sites 2 and 4 (Figure 7 and 9).

Hatching survivals ranged from 18 to 74.5% ($\overline{X}$ = 42.4%) site 1; 9 to 35% ($\overline{X}$ = 24.1%) site 2; 11 to 57% ($\overline{X}$ = 27.5%) site 3; and 3 to 43.5% ($\overline{X}$ = 24.5%) site 4 (Table 1). Alevin lengths ranged from 24 to 33 mm. Mean embryo survival at each site was inversely related to the cumulative period of dewatering ($r^2 = 0.956$). Similar analysis utilizing individual redd survivals and periods of dewatering resulted in a much reduced yet significant relationship ($r^2 = .1277$, $P \leq 0.005$). Percentage of the incubation period each redd was dewatered ranged from 0 to 14% site 1; 0 to 53% site 2; 0 to 31% site 3; and 0 to 48% site 4 (Figure 14). Correlational analysis between the maximum duration of redd dewatering and egg survival also indicated a significant relationship although once again r^2 values were very low ($r^2 = .0626$; $P \leq 0.05$).

Analysis of the redd substrate samples indicated a high percentage of fine material < 4.6 mm present in the gravel. Average percentages found in the four sites were 37.8% site 3; 37.4% site 1, 27.5% site 4; and 21.9% site 2. Material < 0.84 mm averaged 10.5% site 3; 8.5% site 4; 8.2% site 2; and 7.6% site 1 (Table 2). Intragravel intrusion of sediment was evidenced by the large amounts of sediment < 0.84 mm found within the W-V boxes at

TABLE 1. Number of Dead Eggs, Dead and Live Alevins and Estimated Percent Survival Within The 10 Artificial Fall Chinook Redds from the 4 Study Areas Located in the Hells Canyon Reach of the Snake River, Winter 78-80.

Site No.	Redd No.	Box No.	# Dead Eggs	# Dead Alevins	# Live Alevins	Mean Total Length mm	Estimated % Survival to Hatch	Total Days Dewatered
	1	1	76	8	0	--	24	3.33
		2	44	31	2	29.2	56	
		$\overline{X}$					40.0	
	2		75	11	0	--	--	0.5
			89	1	0	--		
							18.0	
	3	1	57	7	0	--	43	0
		2	56	3	0	--	44	
		$\overline{X}$					43.5	
	4		69	10	0	--	31	
			77	0	0	--	23	14.9
							27.0	
	5		15	54	0	--	85	0
			36	20	2	27.0	64	
							74.5	
	6	1	66	3	0	--	34	3.33
			52	11	0	--	48	
							41.0	
	7		43	11	2	29.5	57	0
			52	3	0	--	48	
							52.5	
	8		54	7	11	29.25	46	0
			68	7	2	29.25	32	
							39.0	
	9	1	1/	1/	1/	--	1/	0
			1/	1/	1/	--	1/	
	10		46	2	1	31	54	0
			62	3	0	--	38	
							46.0	
	$\overline{X}$ Overall						42.4	

TABLE 1 (Con't.)

Site No.	Redd No.	Box No.	# Dead Eggs	# Dead Alevins	# Live Alevins	Mean Total Length mm	Estimated % Survival to Hatch	Total Days Dewatered
2	1	1	65	5	0	--	35	27.1
		2	78	6	0	--	22	
		$\bar{X}$					28.50	
	2	1	95	0	0	--	5	43.2
		2	87	0	0	--	13	
		$\bar{X}$					9.0	
	3	1	68	0	0	--	32	56.1
		2	62	0	0	--	38	
		$\bar{X}$					35.0	
	4	1	75	12	0	--	25	28.8
		2	75	3	0	--	25	
		$\bar{X}$					25.0	
	5	1	70	6	7	28.25	30	0
		2	1/	1/	1/	--	1/	
		$\bar{X}$					30	
	6	1	68	0	0	--	32	44.3
		2	87	2	0	--	13	
		$\bar{X}$					22.5	
	7	1	95	0	0	--	5	35.7
		2	80	6	0	--	20	
		$\bar{X}$					12.5	
	8	1	1/	1/	1/	--	1/	5.7
		2	1/	1/	1/	--	1/	
		$\bar{X}$						
	9	1	75	0	0	--	25	46.9
		2	64	0	0	--	36	
		$\bar{X}$					30.5	
	10	1	1/	1/	1/	--	1/	0
		2	1/	1/	1/	--	1/	
		$\bar{X}$						
	$\bar{X}$ Overall						24.1	

TABLE 1. (Con't.)

Site No.	Redd No.	Box No.	# Dead Eggs	# Dead Alevins	# Live Alevins	Mean Total Length mm	Estimated % Survival to Hatch	Total Days Dewatered
3	1	1	50	19	0		50	6.2
		2	80	3	0		20	
		$\bar{X}$					35.0	
	2		96	2	0	--	4	31.5
			78	6	0	--	22	
							13.0	
	3	1	79	0	0		21	33.0
		2	60	0	0		40	
		$\bar{X}$					30.5	
	4	1	1/	1/	1/		1/	28.8
		2	1/	1/	1/		1/	
		$\bar{X}$						
	5	1	78	2	0	--	22	0
		2	87	9	1	24.0	13	
		$\bar{X}$					17.5	
	6	1	56	8	0		44	0
		2	87	4	0		13	
		$\bar{X}$					28.5	
	7	1	94	1	0			33.0
		2	84	2	0			
		$\bar{X}$						
	8	1	1/	1/	1/		1/	28.8
		2	1/	1/	1/		1/	
		$\bar{X}$						
	9	1	43	31	0		57	33.0
		2	43	29	0		57	
		$\bar{X}$					57.0	
	10	1	1/	1/	1/		1/	0
		2	1/	1/	1/		1/	
		$\bar{X}$						
	$\bar{X}$ Overall						27.5	

TABLE (Con't.

Site No.	Redd No.	Box No.	# Dead Eggs	Dead Alevins	# Live Alevins	Mean Total Length mm	Estimated % Survival to Hatch	Total Days Dewatered
4	1	1	84	1	0		16	50.7
		2	94	1	0		6	
		$\overline{X}$					11.0	
	2	1	100	0	0		0	38.2
		2	94	3	0	-	6	
		$\overline{X}$					3.0	
	3	1	73	6	0	--	27	26.5
		2	54	0	0	--	46	
		$\overline{X}$					36.5	
	4	1	56	5	0	--	46	23.2
		2	74	2	0	--	26	
		$\overline{X}$					36.0	
	5	1	60	10	0	--	40	0
		2	88	3	0	--	12	
		$\overline{X}$					26.0	
	6	1	53	20	0	--	47	26.5
		2	60	2	1	33.0	40	
		$\overline{X}$					43.5	
	7	1	100	0	0	--	0	33.8
		2	84	0	0	--	16	
		$\overline{X}$					8.0	
	8	1	61	12	0	--	39	0
		2	85	2	0	--	15	
		$\overline{X}$					27.0	
	9	1	70	7	2	29.75	30	0
		2	86	2	1	27.0	14	
		$\overline{X}$					22.0	
	10	1	60	0	0	--	40	31.5
		2	75	8	0	--	25	
		$\overline{X}$					32.5	
	$\overline{X}$ Overall						24.5	

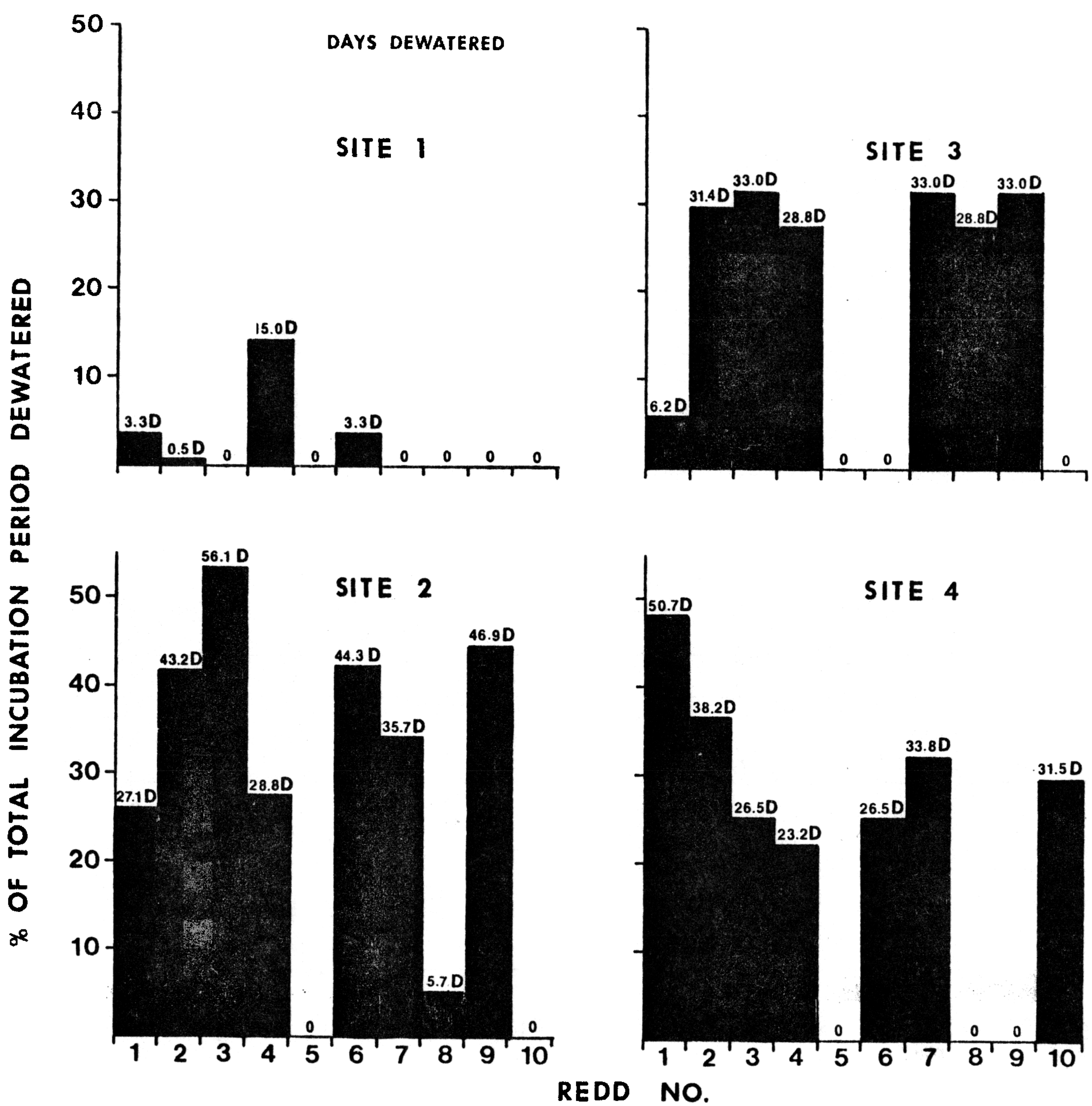


FIGURE 14. Percentage of Total Incubation Period (11/14/79 - 2/23/80) Artificial Fall Chinook Redds Were Dewatered. Values at the Top of Bar Graphs are Total Cumulative Days (D) Dewatered. Hells Canyon - Snake River, Winter 1979-80.

Table 2. Substrate Composition Of Artificial Redds From The Four Study Areas On The Snake River Within Hells Canyon. Fall 1979.

Percent Volume of Material Passing Through Sieve Size (mm) Indicated.

Site No.	Redd No.	76.2	50.8	25.4	12.7	6.4	4.6	3.35	1.70	0.84	0.42
1 Upper Suicide	1	100	95.55	78.73	56.88	44.0	40.56	37.78	26.76	10.52	0.35
	2	100	100	85.93	62.29	48.22	43.90	37.52	22.70	5.56	1.06
	3	100	93.63	79.08	59.14	43.12	38.05	32.82	21.38	6.18	0.62
	4	100	100	93.22	77.05	62.44	57.92	52.88	29.40	6.44	0.70
	5	100	100	81.72	58.32	44.29	38.35	34.22	22.69	7.56	2.61
	6	100	93.13	80.37	56.87	44.32	43.09	41.72	37.27	14.02	6.25
	7	100	100	75.05	50.57	33.60	28.54	24.68	17.28	7.00	1.33
	8	100	86.09	55.40	35.47	22.50	19.92	16.85	10.71	4.37	0.89
	9	100	100	70.80	50.77	37.85	32.42	28.11	18.00	7.14	0.78
	10	100	98.6	72.41	50.56	36.15	31.03	27.10	19.25	7.81	0.98
	$\overline{X}$	100	96.70	77.27	55.79	41.65	37.38	33.37	22.54	7.66	1.61
2 Lower Suicide	1	100	89.14	62.32	45.48	31.74	26.42	21.54	16.66	8.46	1.15
	2	100	82.86	64.69	49.39	37.34	32.94	27.97	20.32	10.56	1.76
	3	100	71.20	45.30	32.35	25.39	22.30	19.98	16.11	9.35	1.04
	4	74.34	63.15	41.97	30.78	23.05	19.43	15.87	10.89	6.25	1.30
	5	84.75	77.48	56.20	41.31	29.25	25.10	20.49	15.35	7.90	2.23
	6	83.53	76.50	57.42	44.16	34.92	32.51	29.09	13.62	4.78	0.48
	7	100	86.64	59.50	41.84	27.19	23.53	20.30	14.05	6.94	0.69
	8	100	82.98	60.12	46.02	33.30	25.48	20.78	17.02	9.35	1.93
	9	100	74.23	58.60	46.56	35.79	32.75	27.68	20.71	12.05	3.39
	10	82.09	57.55	38.18	28.66	22.86	19.10	15.78	13.24	5.89	0.95
	$\overline{X}$	92.47	76.17	54.43	40.66	30.08	25.96	21.95	15.80	8.15	1.49

TABLE 2. Substrate Composition of Artificial Redds From the Four Study Areas on the Snake River Within Hells Canyon. Fall 1979. (Con't.)

Percent Volume of Material Passing Through Sieve Size (mm) Indicated.

Site No.	Redd No.	76.2	50.8	25.4	12.7	6.4	4.6	3.35	1.70	0.84	0.42
3 High Range	1	100	97.42	80.42	66.86	50.37	39.18	26.70	19.60	10.34	2.81
	2	100	100	80.62	70.51	62.08	58.48	54.15	45.72	14.54	3.75
	3	100	91.17	79.48	67.41	56.10	51.33	47.85	37.59	13.59	3.81
	4	100	100	81.36	54.46	36.08	30.66	26.42	17.06	12.02	3.80
	5	100	100	70.26	55.87	42.65	35.65	29.04	17.19	5.91	0.66
	6	100	90.64	81.55	68.45	58.29	54.55	49.47	40.65	15.25	2.95
	7	100	93.13	79.39	43.98	32.09	27.22	21.78	13.32	5.92	0.79
	8	100	93.64	60.78	35.24	27.65	25.60	22.98	18.88	8.10	1.95
	9	100	90.37	74.23	57.83	43.77	39.24	34.82	28.31	12.69	1.08
	10	100	78.18	34.71	23.01	18.29	16.72	15.24	11.64	6.47	0.85
	$\overline{X}$	100	93.46	72.28	54.36	42.74	37.86	32.85	25.00	10.48	2.25
4 Dug Bar	1	100	94.70	80.47	55.36	38.34	32.48	28.57	18.25	9.60	1.51
	2	100	93.58	82.61	56.39	40.07	33.92	28.30	22.41	10.26	3.84
	3	100	93.35	74.48	46.58	37.31	33.94	30.52	27.43	9.04	0.91
	4	100	96.07	72.20	51.74	36.52	32.59	29.70	22.09	10.81	2.15
	5	100	96.23	40.80	22.81	16.43	14.40	13.36	10.98	5.76	1.41
	6	100	74.48	57.17	38.75	30.54	27.21	24.55	20.33	9.23	1.46
	7	100	85.04	69.92	53.15	37.93	34.27	30.14	23.84	11.20	1.65
	8	89.22	77.20	39.26	21.85	13.97	13.35	11.44	8.54	4.39	0.87
	9	100	77.25	39.91	27.37	22.12	20.02	17.86	16.23	6.31	1.06
	10	100	90.56	65.53	50.60	37.64	32.37	27.54	21.39	8.21	1.84
	$\overline{X}$	98.92	87.85	62.24	42.46	31.09	27.46	24.20	19.15	8.48	1.67

the time of recovery. There was, however, no correlation between egg survival and percentage material < 0.84 mm from the individual redds (r^2 = .00043).

The maximum change in stage at each site was 1.71 m (5.61 ft) for site 1; 2.07 m (6.79 ft) for site 2; 1.95 m (6.40 ft)-site 3; and 1.74 m (5.71 ft) for site 4. Flow increase rates were generally less than 0.30 m/hr (98 ft/hr) although on at least two occasions rates were slightly greater than 0.46 m/hr (1.51 ft/hr). On several occasions the stilling well and water level recorder at site 3 were covered during high periods of flow. Average time of travel water velocities between sites l-2 and 3 was 2.04 m/set (6.69 fps) and between sites 3 and 4, 1.76 m/sec (5.77 fps).

Water depths and velocities over artificial redds varied directly with changes in flow while dissolved oxygen levels were in most cases flow independent (Table 3). Several redds having no surface flow exhibited intragravel oxygen levels greater than 9.0 mg/l. Water surface slopes over the artificial redds were 0.94%- site 3, 0.47%- site 1, 0.44%- site 4, and 0.25%- site 2.

Mean water temperatures were generally l-2 C colder at site 4 than at site 2. Temperatures at site 4 ranged from 1.1 C to 11.1 C, while temperatures at site 2 ranged from 2.2 C to 11.5 C. Maximum air temperatures for site 2 ranged from -7.9 C to 14.3 C, with minimum temperatures from -14 C to 7.2 C. Maximum and minimum values at site 4 ranged from -6.8 C to 5.5 C (Figure 16). Temperatures recorded intragravelly include times when the redds were dewatered as well as watered. At least 13 times during the incubation period, intragravel temperatures at site 2 were at or below 0 C (Figure 15). From 26 January to 3 February maximum and minimum temperatures remained only slightly above 0 C. These periods of low temperatures occurred

TABLE 3. Depth (D)-ft, Mean Velocity (V) (0.6 depth) Fps And Dissolved Ox
Redds At Each Of The 4 Study Sites During Various Levels Of Stag

Depth (D)-ft, Velocity (V)-fps and Dissolved Oxygen (D,O) mg/ℓ

Redd Numb

Site No.	Gage Height	1 D	1 V	1 D.O	2 D	2 V	2 D.O	3 D	3 V	3 D.O	4 D	4 V	4 D.O	5 D	5 V
1	2.90	0.9	1.95	8.2	0.65	2.3	7.9	0.95	1.2	8.2	0.45	1.05	7.8	1.20	1.40
	3.30	1.3	2.4	8.4	1.1	2 2	8.3	1.3	2.2	8.4	0.9	1.8	7.7	1.55	1.75
	3.80	1.85	2.2	9.8	1.5	2.5	9.2	1.6	2.1	8.8	1.3	2.6	8.2	1.9	2.35
	Extragravel D.O. = 8.20														
2	3.50	1.25	0.5	9.8	0.7	1.15	9.6	3/	3/	9.4	1.8	2.15	8.8	2.6	2.2
	4.00	2.0	1.0	10.0	1.5	1.0	9.4	0.4	0.95	9.4	2.5	2.6	2/		2/
	4.50	2.5	0.85	2/	1.9	1.8	9.9	0.8	1.25	9.6	2.8	2.25	2/		2/
	5.00	3.0	1.5	2/	2.4	1.65	2/	1.3	1.7	10.8		2/			2/
	5.50	3.5	1.65	2/	2.9	2.65	2/	2.0	2.15	2/		2/			2/
	5.75	3.5	1.65	2/	3.05	2.1	2/	2.0	2.4	2/		2/			2/
	Extragravel D.O. = 8.70														
3	2.65	0.2	0	9.1		3/			3/		3/	3/	8.9	1.1	1.0
	3.70	1.4	0.55	9.8	3/	3/	9.7		3/		0.7	1.15	9.5	2.2	1.35
	4.20	1.6	0.95	2/	0.1	0	8.8	3/	3/	9.5	1.0	1.15	9.0	2.9	1.35
	4.70	2.15	0.8	2/	0.45	0.4	9.0	0.05	0	9.7	1.4	1.3	8.9	3.35	2.0
	5.2	2.75	1.25	2/	1.10	1.45	8.8	0.65	0.65	9.2	2.05	1.95	2/		2/
	Extragravel D.O. = 8.50														
4	1.90		3/			3/			3/			3/		0.6	1.2
	2.90		3/			3/			3/			3/		1.55	4/
	3.80	3/	3/	9.9	3/	3/	9.8	0.95	1.7	9.2	1.0	2.4	9.2	2.5	3.5
	4.30	0.5	0	9.0	.01	0	9.2	1.35	1.55	8.7	1.45	2.65	8.7		2/
	4.80	0.65	0.5	9.8	0.45	1.2	9.6	1.8	2.5	2/	1.85	2.9	2/		2/
	Extragravel D.O. = 10.80														

1/ Standpipe dislodged

2/ Water depth too deep to allow measurement

3/ Redd exposed

4/ Not measured

* 1 foot = .3048 meter

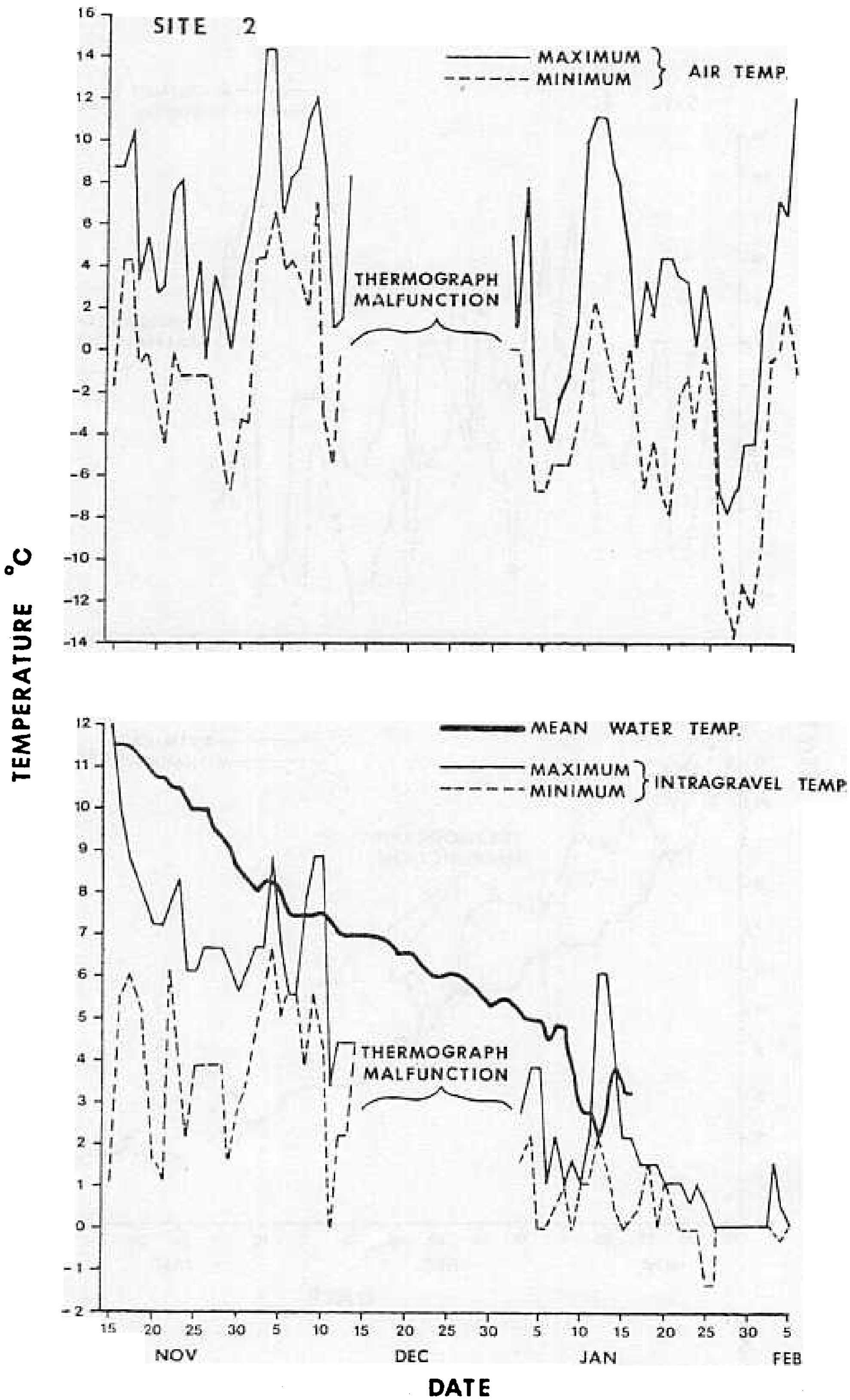


FIGURE 15. Air, Water and Intragravel Temperatures Recorded at Study Site No. 2, Within Hells Canyon, Snake River, Nov. 15 - Feb 5, 1979-80.

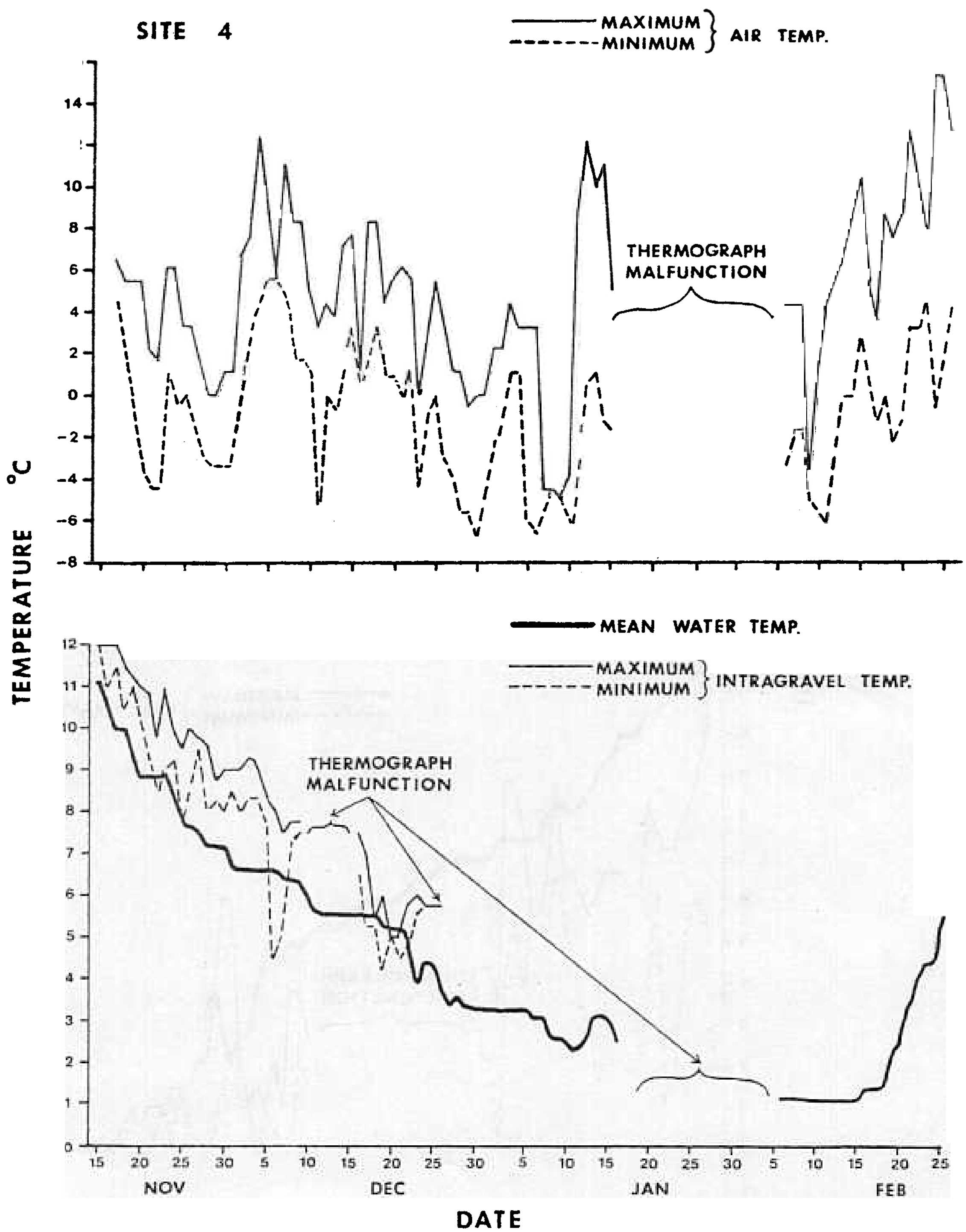


FIGURE 16. Air, Water, and Intragravel Temperatures Recorded at Study Site No. 4 Within Hells Canyon, Snake River, Nov. 15 - Feb. 25, 1979-80.

TABLE 4. Percent Spring Chinook Egg Survival From Artificial Redds Exposed To Constant (Control) and Simulated Peaking Flows (Test) In The Hayden Creek Channels. Fall 1979.

Redd No	Channel	% Sec < 0.84 mm	Percent Egg Survival				Mean $\bar{X}$
			Box 1	Box 2	Box 3	Box 4	
1	Control C	0.44	47.0	66	19	27	39.7
	Test T	0.59	90	61	89	85	81.2
2	C						
	T						
3							
Mean $\bar{X}$							
4	C	2.79	68	68	79	79	73.5
	T	1.65	87	83	90	89	87.2
5							
6							
Mean $\bar{X}$							
7	C	1.93	90	86	92	89	89.2
	T	4.25	48	75	80	60	65.7
8	C	4.97	88	92	85	86	87.7
	T	3.73	73	49	65	55	60.5
9	C	5.78	89	68	49	87	73.2
	T	4.10	57	16	44	25	35.5
Mean $\bar{X}$	C	4.23	89	82	75.3	87.3	83.4
							53.9
10	C	2.15	83	89	80	88	85
	T	4.85	58	67	65	64	63.5
11	C						
	T						
12							
Mean $\bar{X}$	C						
	T						
OVERALL Mean $\bar{X}$	C		73.8	74.9	71.3	77.7	74.4
	T		72	65.7	73	67.8	69.6

when the redds were dewatered. Because of equipment failure, intragravel temperatures at site 4 were not recorded after 27 December. The records from site 2 indicate that the potential for intragravel freezing of embryos within dewatered redds is possible. However, we found no broken water filled vials in any of the redds to indicate that freezing had occurred and influenced egg survival

Laboratory Tests

Spring chinook salmon embryo survival, evaluated on 30 November 1979, averaged greater than 50% for both control and test channels (Table 4). Test channel redds 1-6 were cumulatively dewatered 31.5 days, redds 7-12, 30 days. This differential occurred since there was an approximate 1 hour delay before embryos were dewatered in the lower channel. Embryo survival in test channel riffles 1 and 2 was higher than in the control, while the reverse occurred in riffles 3 and 4. Overall, percent embryo survival within the 4 riffle areas was dependent on flow regime (X^2 = 16.04: df=3; $P \leq 0.05$). However, variance testing between control and test riffles indicated no significant difference in variances for all riffles except number 1 ($F= 6.95$; $df_{1,2}=11$; $P \leq 0.05$), in which the control variance was larger than the test (Table 5).

Table 5. Results of Variance Testing Between Control and Task Channel Embryo Survival For The Spring Chinook Flow Fluctuation Tests, Hayden Creek Channels - Fall 1979.

Riffle	s^2 control	s^2 test	s_1^2/ s_2^2
1	486.02	69.97	6.95
2	55.30	32.52	1.70
3	156.82	66.1	2.37
4	42.08	34.00	1.24

TABLE 5 Substrate Composition of Artificial Spring Chinook Redds From the Control And Test Channels At The Hayden Creek Research Station. Fall 1979.

		Percent volume of material passing through sieve size (mm) indicated									
Redd No.	Channel	76.2	50.8	25.4	12.7	6.4	4.6	3.35	1.70	0.84	0.42
1	Control C	100	79.59	5.62	2.11	2.11	1.01	0.61	0.43	0.43	0.30
	Test C	100	83.78	3.09	1.71	0.70	0.70	0.70	0.70	0.59	0.59
2	C	100	92.86	3.49	1.77	1.47	1.47	1.47	1.32	1.22	1.22
	T	100	100	4.17	1.38	1.38	1.38	1.38	1.38	1.25	1.16
3	C	100	86.23	2.55	0.30	0.19	0.19	0.19	0.19	0.19	0.19
	T	100	100	2.81	1.16	0.98	0.85	0.85	0.85	0.76	0.67
X̄	C	100	86.23	3.89	1.39	1.26	0.89	0.76	0.65	0.61	0.57
	T	100	94.59	3.36	1.42	1.02	0.98	0.98	0.98	0.87	0.81
4	C	100	100	42.50	33.63	24.68	18.31	12.94	6.37	2.79	0.80
	T	100	87.29	25.10	22.92	15.34	11.33	7.32	2.73	1.66	0.72
5	C	100	94.20	31.03	26.03	19.03	14.23	9.23	4.71	2.51	1.59
	T	100	90.23	37.21	32.48	23.93	16.48	10.13	5.31	2.24	1.06
6	C	100	100	16.12	13.85	8.30	6.50	3.86	1.64	1.01	0.48
	T	100	84.16	45.34	38.77	33.17	26.41	20.81	10.0	4.98	1.70
X̄	C	100	98.07	29.88	24.50	17.34	13.01	8.68	4.24	2.10	0.96
	T	100	87.23	35.88	31.39	24.15	18.07	12.75	6.01	2.96	1.16
7	C	100	95.17	40.95	37.37	24.84	16.97	11.06	5.33	1.93	0.82
	T	100	100	42.94	37.17	29.22	20.47	15.30	8.34	4.24	1.54
8	C	100	100	52.82	45.89	36.04	27.51	21.07	9.70	4.96	1.28
	T	100	93.85	33.94	28.95	21.49	17.90	13.52	7.69	3.73	1.07
9	C	100	100	49.43	44.17	36.20	27.94	20.16	12.08	5.78	1.59
	T	100	100	38.51	35.95	29.54	25.51	17.64	8.67	4.09	1.09
X̄	C	100	98.39	47.73	42.48	32.36	24.14	17.43	9.04	4.22	1.23
	T	100	97.95	38.46	34.02	26.75	21.29	15.49	8.23	4.02	1.23
10	C	100	94.89	28.16	22.79	16.88	12.85	8.73	4.70	2.15	0.99
	T	100	100	48.61	43.53	34.54	26.72	20.47	10.70	4.84	1.83
11	C	100	100	58.60	53.09	42.47	36.71	26.27	17.45	9.89	3.23
	T	100	96.35	48.50	41.01	33.71	27.14	20.57	12.35	6.32	1.75
12	C	100	100	58.16	52.97	45.74	39.61	30.33	20.11	9.35	2.30
	T	100	96.90	49.41	40.60	30.17	24.58	18.06	13.71	3.90	1.29
X̄	C	100	98.30	48.31	42.95	35.03	29.72	21.78	14.09	7.13	2.17
	T	100	97.75	48.84	41.71	32.81	26.15	19.70	12.25	5.02	1.62

Embryo survival within control riffle 1 may have been influenced by extraneous factors (e.g. handling mortality) not affecting the others. With the elimination of these survival values, percent survival is independent of flow regime ($X^2 = 7.61$; df=3; $p<0.05$), i.e. embryo survival was not significantly different between the control and test channels.

Embryo survival in the control channel was largely unrelated to sediment level ($r^2 = .0067$) even though levels < 0.84 mm tended to be higher than in the test channel (Figure 17, Table 6). In contrast, survival in the test channel was more related to sediment level ($r^2 = 0.424$). Based on sediment, the greatest reduction in embryo survival in the test channel occurred with levels of 4-5% material < 0.84 mm, and 20-21% < 4.6 mm. No reduction in survival was observed in the control channel with similar levels (Figure 18).

Water depths and velocities over control redds during the peaking hours ranged from 6.1 to 9.4 cm and 0 to 10.67 cm/set (2.4 to 3.7 inch and 0 to .35 Fps); during nonpeaking hours, from 6.1 to 12.19 cm and 0 to 18.29 cm/set (2.4 to 4.8 inch and 0 to .60fps)(Table 7). The 0 velocities resulted from the redds being positioned directly posterior to each other causing backwater areas. Average time of travel velocities ranged from 9.2 to 10.9 cm/set (.30 to .36fps) (peaking), and 14.00 cm/set (.46 fps) (nonpeaking)(Table 8). Depths and velocities over test channel redds (peaking) ranged from 4.57 to 9.14 cm (1.8 to 3.6 inch) and 0 to 18.29 cm/set (0 to .60 fPs). Intragravel dissolved oxygens tended to be lower in the control channel (range 1.0 to 6.6 mg/l; $\overline{X} = 4.18$) than in the test (range 4.4 to 6.3 mg/l; $\overline{X} = 5.5$), especially in the upper redds where sediment levels were low (Table 7). However, large blankets of periphyton overlayed these redds

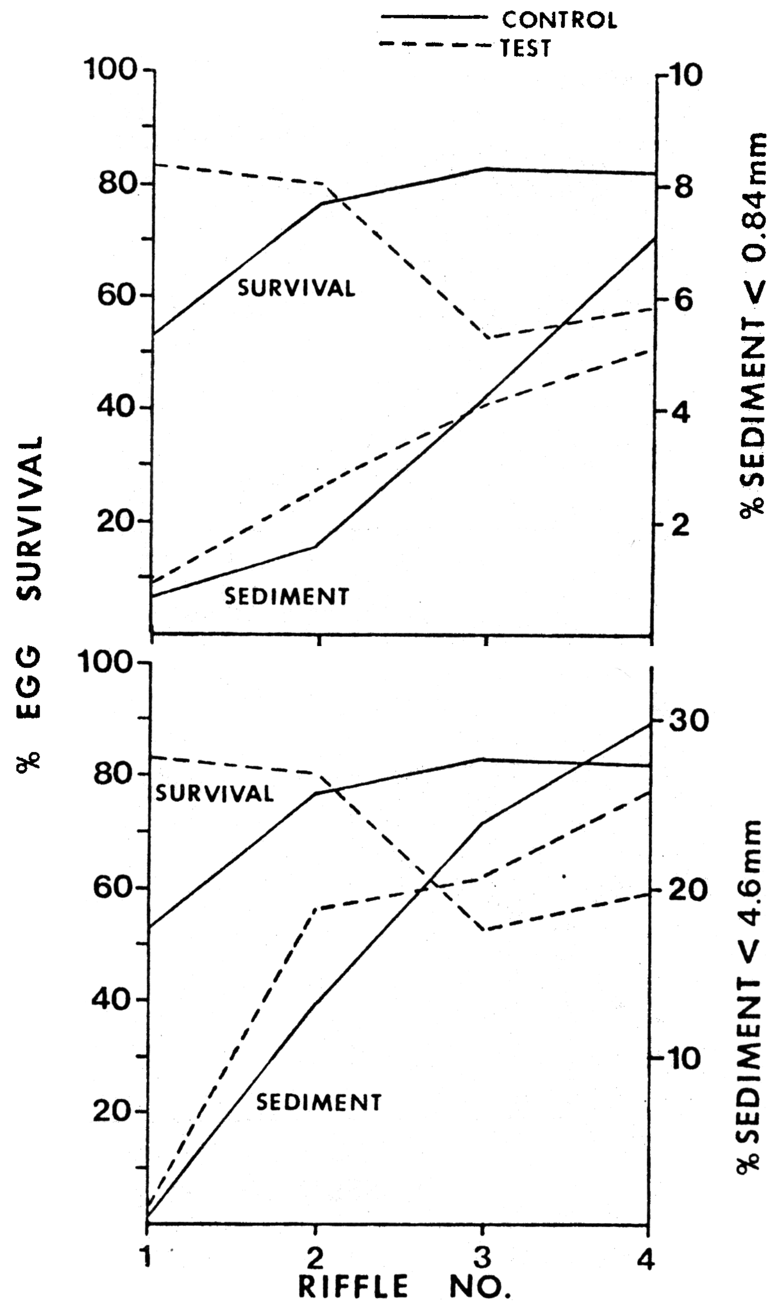


FIGURE 17. Percent Spring Chinook Embryo Survival and Associated Percent Sediment < 0.84 mm and < 4.6 mm From Control and Test Flow Condition, Hayden Creek Research Station, Fall 1979.

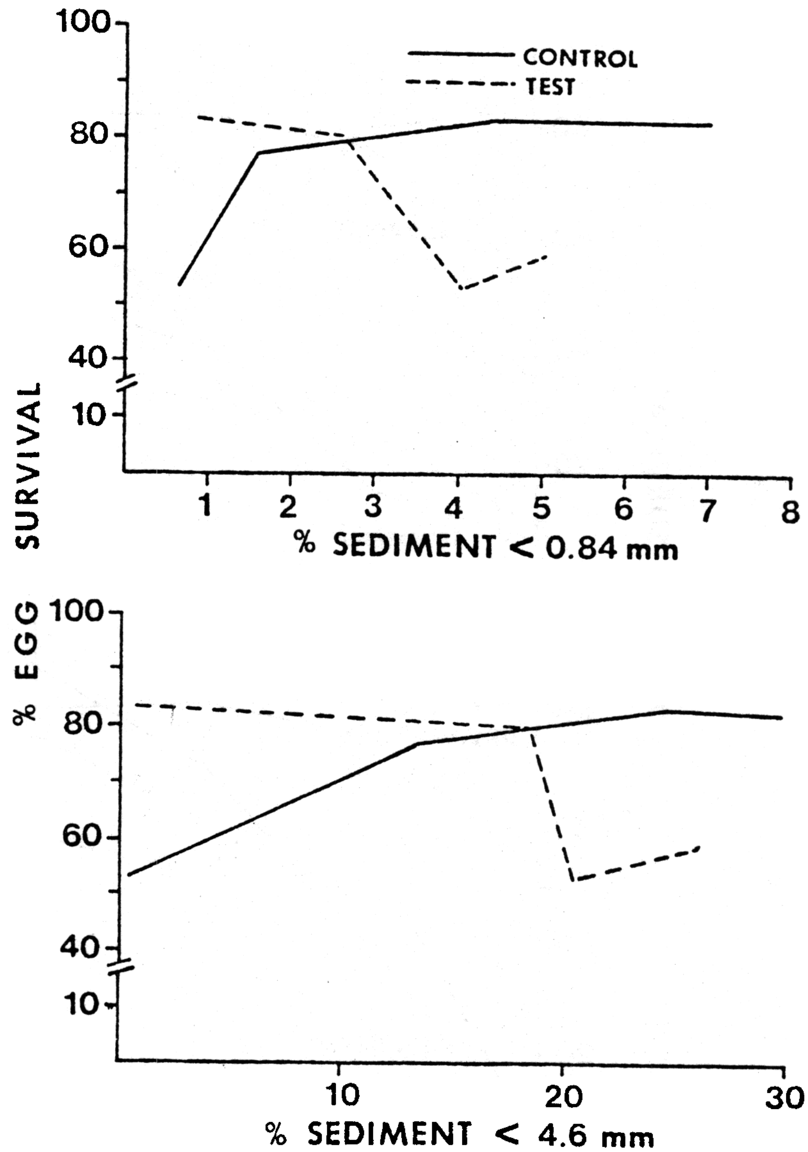


FIGURE 18. Relationship Between Spring Chinook Embryo Survival and Percent Sediment < 0.84 mm and < 4.6 mm From Control and Test Flow Condition, Hayden Creek Research Station, Fall 1979.

TABLE 6. Physical, Chemical And Hydraulic Parameters Associated With Artificial Spring Chinook Redds Exposed To Constant (Control) And Fluctuating Flows (Test) During Nonpeaking And Peaking Hours. Hayden Creek Channels. Fall 1979.

Redd No.	Channel	< 0.84mm	Water Depth (cm) (Peaking)	Water Depth {cm) (Nonpeaking)	Water Velocity (cms) (Peaking)	Water Velocity (cms) (Nonpeaking)	Dissolved oxygen ms/1 11/4	11/9
1	Control C	0.44	9.14	12.19	6.10	10.67	5.2	5.7
	Test T	0.59	6.10	--	13.72	--	5.6	5.4
2	C	1.23	7.62	10.67	4.57	7.62	2.3	3.0
	T	1.25	6.10	--	0	--	5.9	6.0
3	C	0.19	6.10	7.62	0	3.05	1.7	1.0
	T	0.76	6.10	--	0	--	5.7	5.9
4	C	2.79	9.14	12.19	3.05	10.67	2.5	1.4
	T	1.65	9.14	--	12.19	--	5.3	5.9
5	C	2.52	7.62	9.14	3.05	3.05	3.3	2.1
	T	2.23	7.62	--	1.52	--	5.2	6.2
6	C	1.01	9.14	12.19	3.05	3.05	4.4	2.3
	T	4.98	9.14	--	0	--	5.2	4.4
7	C	1.93	6.10	9.14	7.62	15.24	5.6	5.8
	T	4.25	6.10	--	13.72	--	5.2	5.8
8	C	4.97	6.10	6.10	9.14	15.24	5.9	6.6
	T	3.73	6.10	--	7.62	--	5.2	5.9
9	C	5.78	6.10	7.62	0	0	4.8	4.8
	T	4.10	9.14	--	0	--	4.9	5.1
10	C	2.15	6.10	7.62	10.67	18.29	5.6	5.5
	T	4.85	6.10	--	15.24	--	5.0	5.4
11	C	9.90	9.14	7.62	6.10	13.72	5.5	5.6
	T	6.32	4.57	--	18.29	--	5.4	5.9
12	C	9.35	6.10	9.14	6.10	10.67	5.0	4.8
	T	3.91	6.10	--	7.62	--	5.8	6.3

1 cm = 0.3937 inch

Table 7. Discharge and Resulting Average Velocities For The Control And Test Channels As Determined Using Fluorescent Dye Time Of Travel Techniques, Hayden Creek Research Station, Fall-Winter 1979-80.

Channel	Flow 1/ Flow 1/m Peaking	Nonpeaking	Average Velocity cm/sec. Peaking	Nonpeaking	
Upper Control	1021.2	1269.6	10.90	14.99	
Upper Test	1021.2		11.99		Spring
Lower Control	1021.2	1269.6	9.22	14.99	
Lower Test	1021.2	--	10.90		

Channel	Flow 1/m Peaking	Nonpeaking	Average Velocity cm/sec. Peaking	Nonpeaking	
Upper Control	171.8	873.6			Fall
Upper Test	171.8				Chinook
Lower Control	171.8	873.6			Tests
Lower Test	171.8				

Channel length = 1798 cm

which may have reduced intragravel velocities and oxygen replenishment. Test channel riffles had no epilithic algae.

Mean water temperatures ranged from 11.4 C to 0.84 C. Water temperatures averaged approximately 1.7 C during most of November. Maximum air temperature was 26.9 C while minimum was -8.9 C. The minimum air temperature during the peaking schedule was -5.6 C which occurred when the riffles were dewatered; intragravel temperature (riffle 4 - test) at this time was 5.6 C. The minimum temperature recorded for the intragravel environment during periods of dewatering was 3.36 C. In general, dewatered intragravel temperatures remained 1-2 C higher than the water temperature, with the maximum difference occurring just prior to flow restoration. We found no evidence of intragravel freezing during periods of dewatering, as no water filled vials were broken.

In all riffles, alevins were longer and heavier from flow fluctuation channel (test). Both lengths and weights of alevins from the test channel tended to increase with increased sediment while those from the control increased through riffle 3 and then decreased as sediment level increased (Figure 19). Mean lengths and weights of alevins from the control ranged from 22.16 to 24.30 mm (.87 to .96 inch) and 288.0 to 371.0 mg, while those from the test ranged from 24.02 to 27.07 mm (.95 to 1.07 inch) and 292.0 to 341.0 mg respectively (Table 8). Overall, test channel alevins were significantly longer ($P < 0037$) and heavier ($P < .0391$) than alevins from the con-

There was no significant difference in alevin length ($P > .1586$ or weight (P .6255) among the four riffles

After rearing for 53 days, there was no significant difference in fry length between the control ($\overline{X} = 60.93$ mm) and test ($\overline{X} = 59.93$) channel ($P \geq 0.10$). Mean weights at the end of the rearing period were 1.68 gm for con-

alevins and 1.78 gm for test alevins, with growth rates of 0.023 and 0.024 gm/day respectively (Figure 20). Overall, there was no significant difference in weight or growth rates between control and test fry during the rearing test (weight- $P > .7897$; growth- $P > .3950$).

Fall Chinook Salmon:

Embryo survival in both channels was very low ($\overline{X}$ controls = 1.29% $\overline{X}$ test = 4.13%) ranging from 0 to 4.0% in the control, and from 0 to 16.0% in the test Table 9) (upper test channels cumulatively dewatered 43 days;

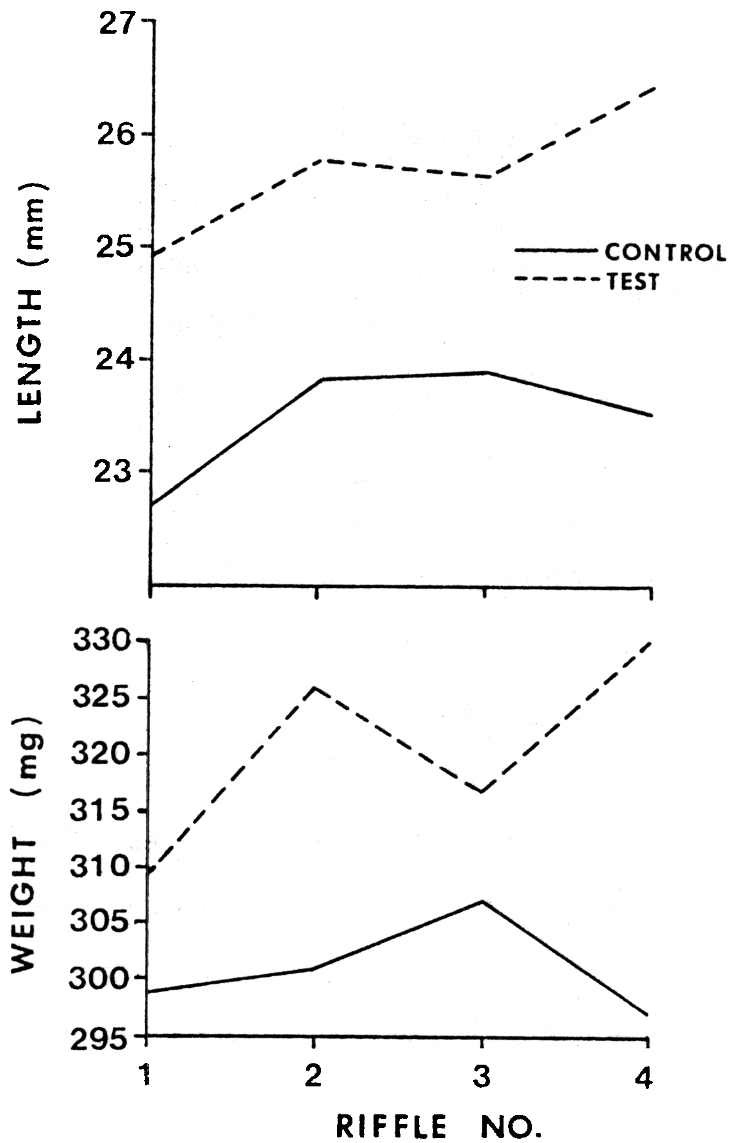


FIGURE 19. Comparison of Mean Length and Weight of Spring Chinook Alevins Resulting From Embryo Incubations in Constant (Control) Versus Simulated Peaking (Test) Flows, Hayden Creek Research Station, Fall 1979.

TABLE 8. Mean Length And Mean Weight Of Spring Chinook Alevins Resulting From Eggs Incubated In Constant (Control Versus Simulated Peaking (Test) Flows In The Hayden Creek Channels. Fall 1979.

Riffle No.	Redd No.	Channel	N	Date Sampled	Mean Total Length (mm)	Variance S^2	Range Length mm	Mean Wet Wt. (mg)
1	1	Control	25	11/30	22.76	4.11	18.5-25.5	296.0
		Test	25	11/30	24.02	2.41	20.5-26.5	303.0
	2	C	25	12/1	22.16	4.39	16.5-24.5	300.0
		T	24	12/1	25.44	1.20	22.5-27.0	315.0
	3	C	28	12/2	23.27	3.68	18.5-25.5	300.0
		T	28	12/2	25.45	2.86	22.5-27.5	311.0
	$\overline{X}$	C	--	--	22.73	--	--	298.7
		T	--	--	24.97	--	--	309.7
2	4	C	26	12/2	23.94	1.65	21.0-26.0	292.0
		T	27	12/2	25.06	1.70	22.0-27.0	323.0
	5	C	29	12/3	23.55	1.35	21.0-25.0	301.0
		T	26	12/3	26.12	1.09	23.5-28.0	327.0
	6	C	25	12/3	24.00	2.33	21.0-26.0	310.0
		T	27	12/3	26.13	2.68	20.0-27.5	328.0
	$\overline{X}$	C			23.83			301.0
		T			25.77			326.0
3	7	C	31	12/3	24.23	2.20	20.0-27.0	309.0
		T	28	12/3	27.07	2.11	23.5-26.5	332.0
	8	C	33	12/3	24.09	1.40	21.0-26.0	317.0
		T	28	12/3	25.20	6.88	19.0-29.0	328.0
	9	C	25	12/3	23.38	2.40	20.0-26.0	297.0
		T	13	12/3	24.69	2.94	21.5-27.0	292.0
	$\overline{X}$	C			23.90			307.7
		T			25.65			317.3
4	10	C	25	12/4	23.33	4.06	17.5-25.5	304.0
		T	34	12/4	26.16	1.81	22.0-28.5	341.0
	11	C	28	12/4	22.89	3.10	19.5-25.5	288.0
		T	21	12/4	26.83	1.63	24.5-28.5	310.0
	12	C	35	12/4	24.30	2.56	19.5-26.5	300.0
		T	26	12/4	26.46	1.82	24.0-28.5	339.0
	$\overline{X}$				23.51			297.3
					26.48			330.0

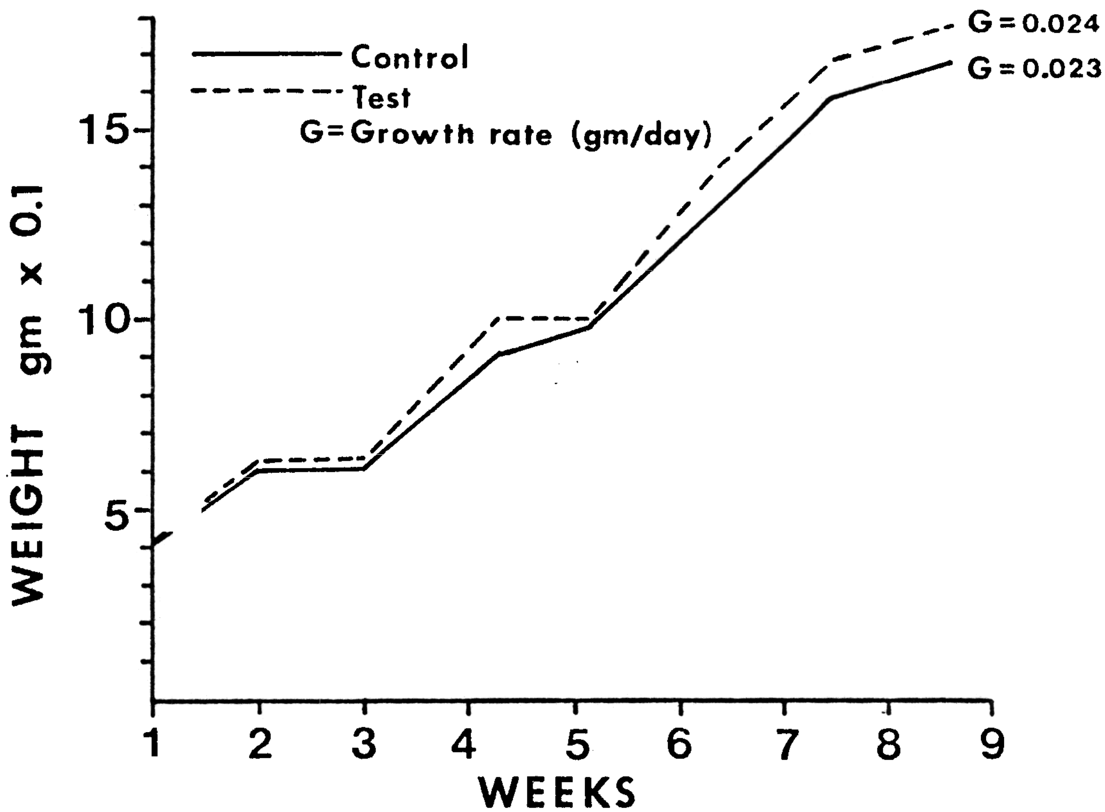


FIGURE 20. Growth Comparisons (weight) of Spring Chinook Salmon Fry Resulting From Embryos Incubated in Control Versus Test Flow Conditions, Hayden Creek Research Station, Fall 1979.

TABLE 9. Percent Fall Chinook Egg Survival From Artificial Redds Exposed To Constant (Control) and Simulated Peaking Flows (Tests) In The Hayden Creek Channels. Winter 1979.

Redd No.	Channel	Box 1	Box 2	Box 3	Box 4	Mean $\bar{X}$
		Percent Egg Survival				
1	Control C	3.0	1.0	2.0	2.0	2.0
	Test T	0	0	1.0	1.0	0.50
2	C	3.0	0	3.0	1.0	1.75
	T	0	0	0	0	0
3	C	1.0	--	3.0	2.0	1.50
	T	0	0	3.0	0	0.75
$\bar{X}$	C	--	--	--	--	1.75
	T	--	--	--	--	0.42
4	C	1.0	1.0	1.0	0	0.75
	T	2.0	1.0	6.0	2.0	2.75
5	C	2.0	1.0	0	0	0.75
	T	0	1.0	4.0	0	1.25
6	C	1.0	1.0	2.0	0	1.00
	T	0	0	2.0	0	0.50
$\bar{X}$	C	--	--	--	--	0.83
	T	--	--	--	--	1.50
7	C	0	4.0	1.0	1.0	1.50
	T	10.0	11.0	12.0	8.0	10.25
8	C	4.0	2.0	0	0	1.50
	T	5.0	10.0	4.0	10.0	7.25
9	C	3.0	1.0	1.0	3.0	2.0
	T	4.0	6.0	4.0	5.0	4.75
$\bar{X}$	C	--	--	--	--	1.67
	T	--	--	--	--	7.42
10	C	2.0	2.0	0	0	1.0
	T	16.0	7.0	8.0	2.0	8.25
11	C	1.0	1.0	2.0	3.0	1.75
	T	6.0	6.0	5.0	7.0	6.0
12	C	0	0	0	0	0
	T	4;0	7.0	12.0	6.0	7.25
$\bar{X}$	C	--	--	--	--	0.92
	T	--	--	--	--	7.17
OVERALL $\bar{X}$	C	--	--	--	--	1.29
	T	--	--	--	--	4.13

lower channels 39.4 days A chi-square test of independence indicated no significant difference in embryo survival between the two channels (P = 0.10). We attribute the low survival to handling mortality and not to differences in flow. Due to inclement weather fertilized eggs were not planted in the Hayden Creek channels until 33 hours after they were spawned.

Water temperatures ranged from 2.8 to 7.3 C while air temperatures ranged from -26.9 C to 8.96 C. As in the spring chinook tests, intragravel temperatures during periods of dewatering were generally 1-2 C higher than water temperatures and there was no evidence of intragravel freezing. However, exposed redds were covered with insulation which may have effectivelly prevented freezing. Because of the small sample sizes, we made no fry quality comparisons.

EMBRYO DEWATERING TOLERANCE TESTS

Spring - Fall 1979

Steelhead Tests With the exception of week 1, steelhead embryo hatching survival from both watered and dewatered chambers was relatively constant between sampling weeks (Figure 21) The low hatching success from week 1 was due to handling mortality. Hatching success ranged from 54 to 100% for watered embryos and from 67 to 98% for dewatered (excluding week 1) (Table 10). Overall survival to hatching was independent of incubation in watered or dewatered conditions and the four sediment levels ($P \geq 0.10$) and of watered versus dewatered and the number of weeks dewatered (P 0.10)

Fertilized eggs from the dewatered chambers typically hatched earlier than those from the watered. This was most evident in the chambers dewatered 3 to 4 weeks, where hatching modes differed by as much as 14 days Figure 22)

Mean water temperatures during the incubation period ranged from 3.3 C to 8.5 C (Figure 23). Intragravel temperatures in the dewatered chambers were higher than water temperatures and ranged from 3.3 C to 14.4 C Temperatures within the 10% < 0.84 mm mix averaged higher overall than the others, although this was probably a result of the chamber being exposed to the sun the longest. Maximum temperatures typically occurred between 1200 and 1600 hours while minimum temperatures between 0600 and 0900 hr.

Gravel moisture within the four sediment mixes remained relatively constant throughout all 4 weeks of dewatering (Figure 24). The sediment mix 30% < 4.6 > 0.84 and 20% < 0.84 mm maintained the highest moisture content, $\overline{X}$ = 3.92%. The other two mixes; 20% < 4.6 > 0.84 and 10% < 0.84 mm,

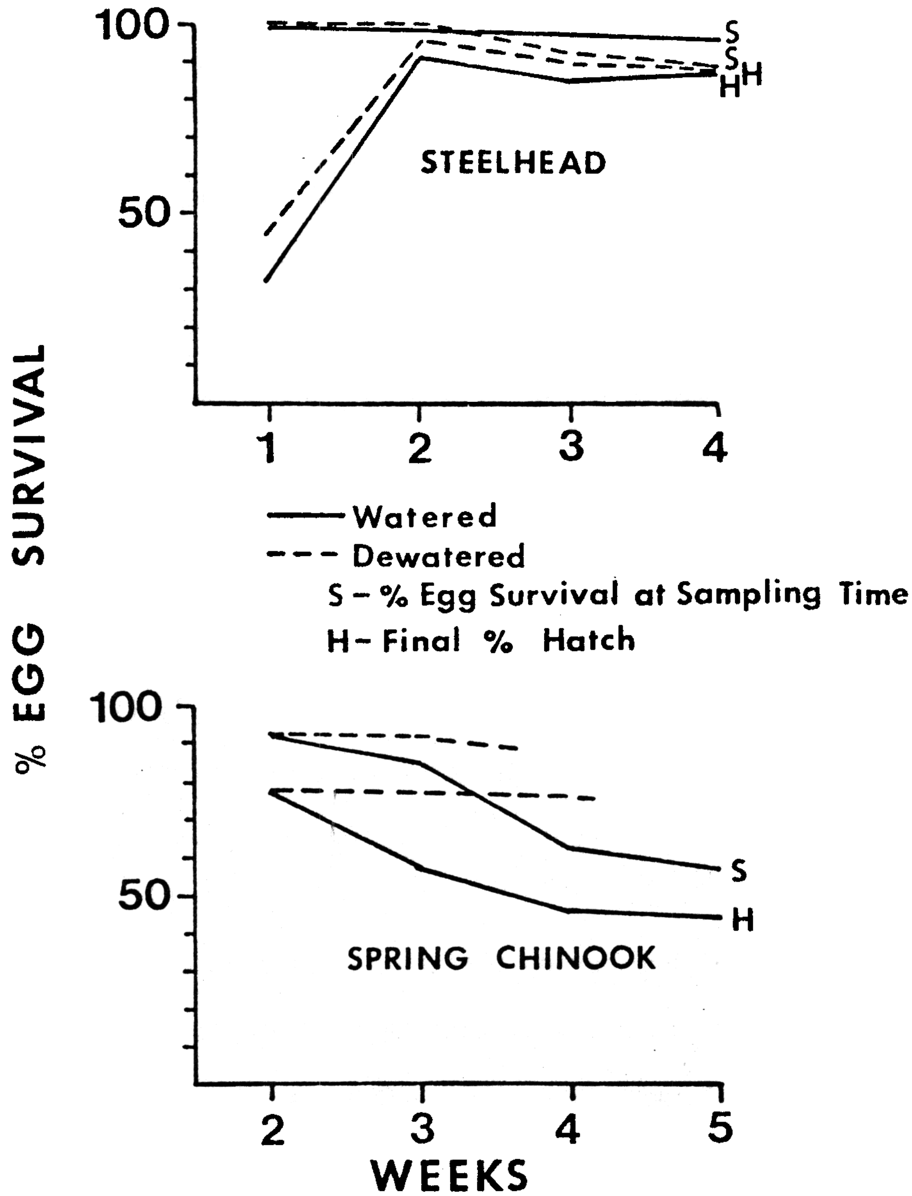


FIGURE 21. Mean Percentage Embryo Survival at Sampling (S) and Final Percent Hatch (H) For Steelhead (Upper) and Spring Chinook (Lower) Dewatering Tests. Steelhead Embryos Were Dewatered 1-4 Weeks, Chinook Eggs 2-5 Weeks, Hayden Creek Research Station, 1979.

TABLE 10. Comparison Of Steelhead Survival And Hatching Success Associated With 1-4 Weeks Of Dewatering (D) With Watered (W) Egg Survivals For Four Different Sediment Mixes. Hayden Creek Research Station. Spring 1979.

Sediment Level	Week 1 W	Week 1 D	Week 2 W	Week 2 D	Week 3 W	Week 3 D	Week 4 W	Week 4 D	Mean $\overline{X}$ W	Mean $\overline{X}$ D	Mean $\overline{X}$ (exclude wks) W	Mean $\overline{X}$ (exclude wks) D
	Percent egg survival (Final percent hatch)											
30% < 4.6 > 0.84 and 20% < 0.84	100 (72)	100 (68)	100 (100)	98 (93.1)	97 (97)	97 (95)	99 (98)	67 (67)	99 (91.7)	90.5 (80.7)	98.7 (98.3)	87.3 (85)
20% < 4.6 > 0.84	99 (19)	100 (39)	99 (73)	99 (98)	97 (73)	97 (93)	100 (97)	100 (98)	98.7 (65.5)	99.0 (82)	98.7 (81)	98.7 (96.3)
20% < 4.6 > 0.84 and 10% < 0.84	99 (28)	100 (50)	100 (100)	100 (98)	97 (91)	94 (82)	99 (98)	91 (91)	98.7 (79.2)	96.2 (80.2)	98.7 (96.3)	95.0 (90.3)
10% < 0.84	100 (13)	100 (23)	98 (93)	100 (97)	100 (82)	95 (91)	90 (54)	98 (97)	97 (60.5)	98.2 (77)	96 (76.3)	97.7 (95)
Mean $\overline{X}$	99.5 (33)	100 (45)	99.2 (91.5)	99.2 (96.5)	97.7 (85.7)	95.7 (90.2)	97 (86.7)	89 (88.2)	98.3 (74.2)	96 (80.0)	98 (88.0)	94.7 (91.6)

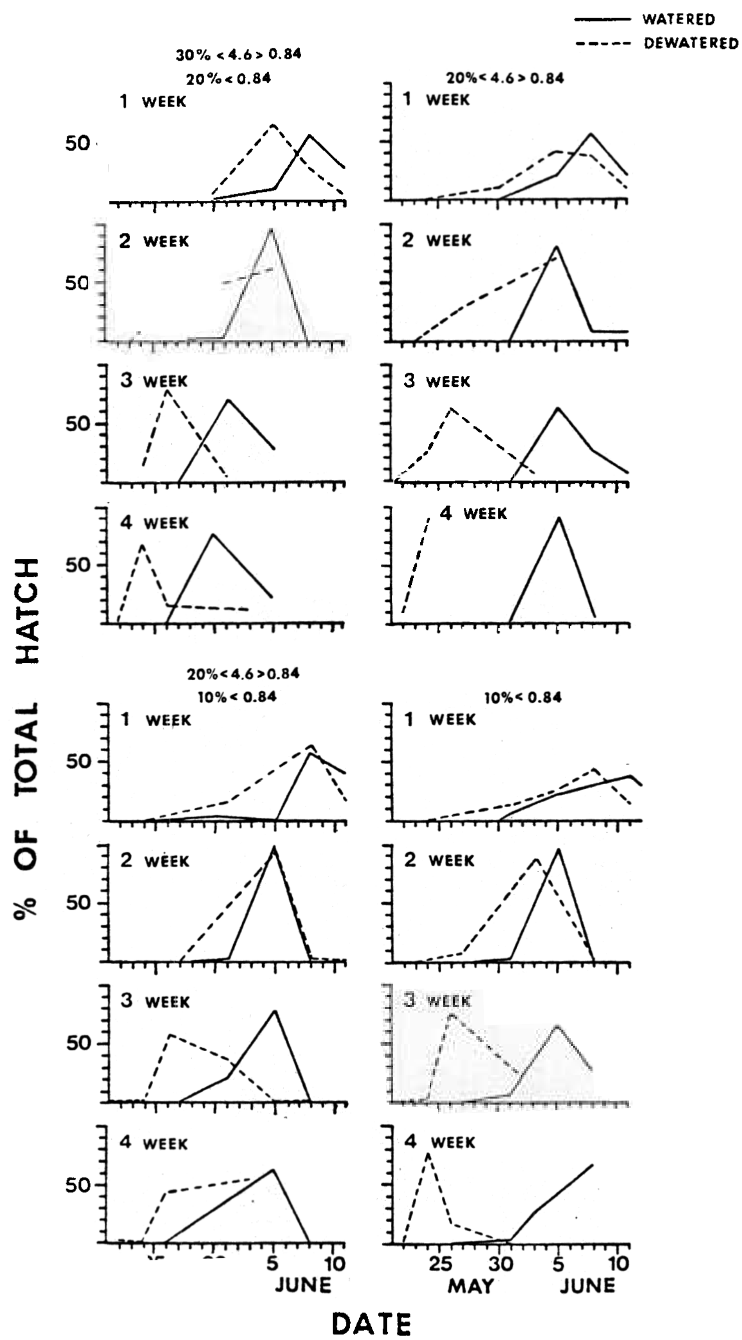


Figure 22. Hatching Chronology of Steelhead Eggs Incubated in Watered or Dewatered Conditions Within Four Sediment Mixtures for 1-4 Weeks Prior to Placement in Heath Stack Incubators. Hayden Creek Research Station. Spring 1979.

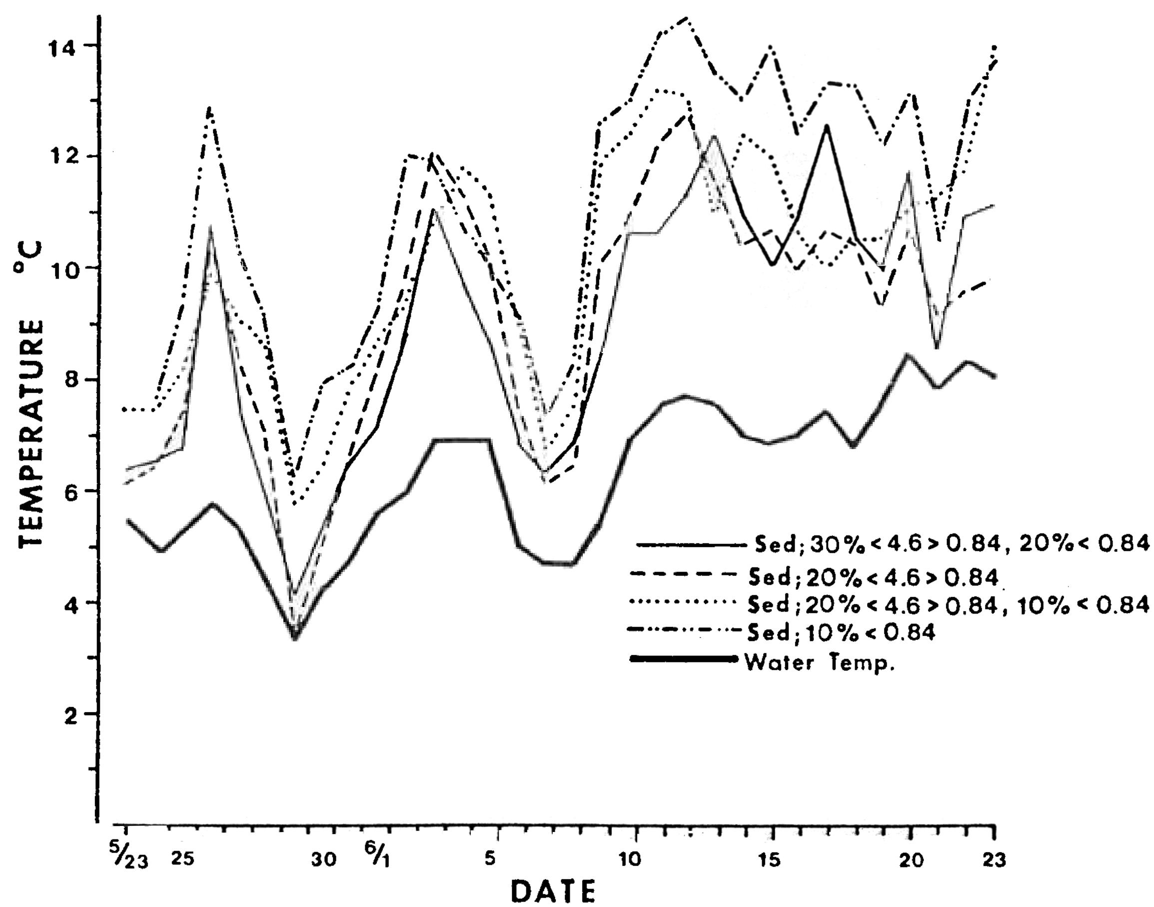


FIGURE 23. Mean Intragravel Temperatures and Water Temperatures From Within 4 Sediment Mixtures During Steelhead Embryo Dewatering Tests. Hayden Creek Research Station. Spring 1979.

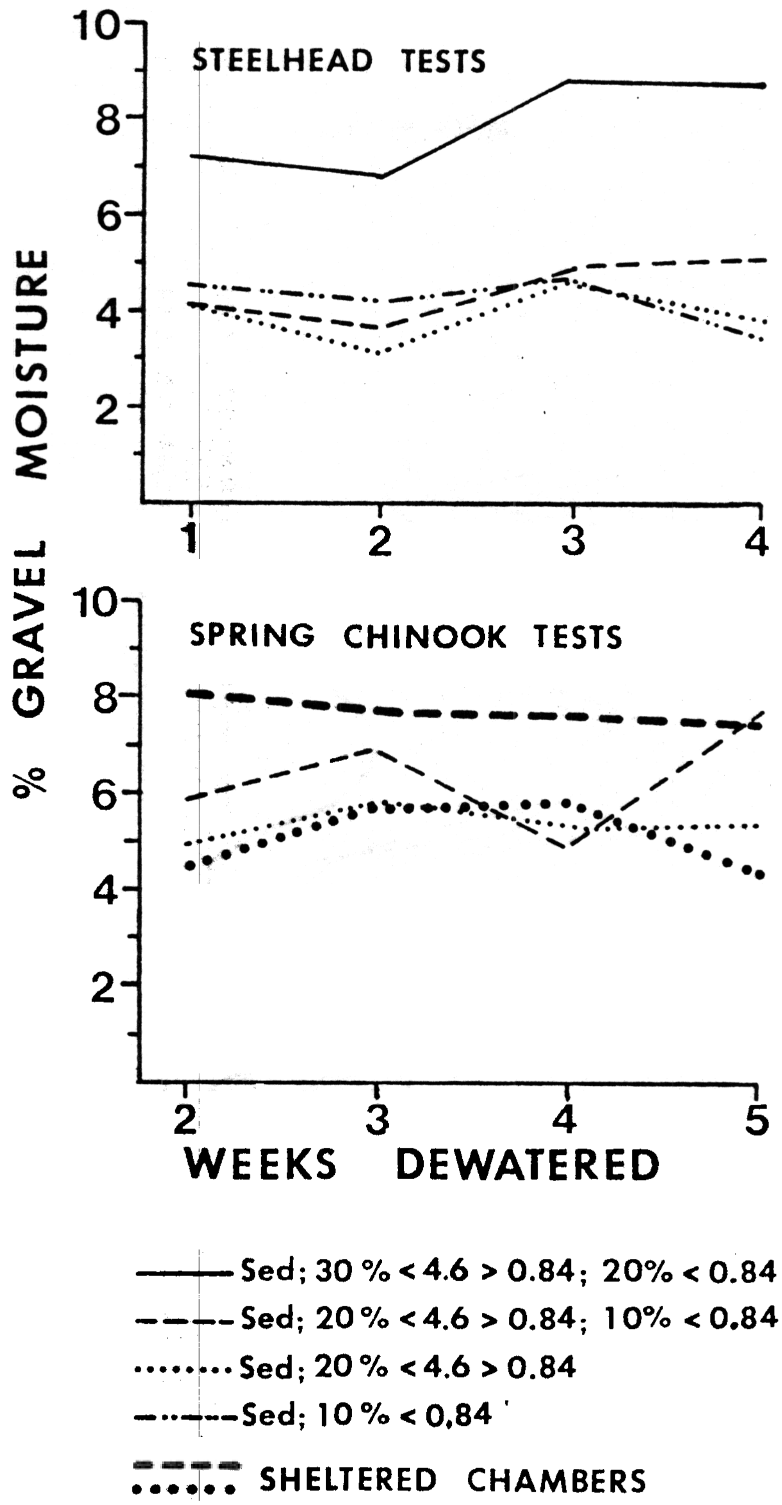


FIGURE 24. Mean Percent Gravel Moisture Retained During Steelhead (1-4 Weeks) and Chinook (2-5 Weeks) Embryo Dewatering Tests. Hayden Creek Research Station. 1979.

and 10% < 0.84 mm averaged 4.48 and 4.23% respectively Gravel moisture may have been influenced by two days of snow showers and 6 days of rain during the tests.

In general, mean alevin lengths were longer from watered versus dewatered chambers while the total weights were approximately equal (Table 12). Differences in length reflect variations in sampling times rather than incubation conditions of watered and dewatered. No statistical comparisons of alevin quality parameters were made, however, it is evident, that there was little difference in length or weight between alevins from eggs subjected to from 1-4 weeks of dewatering.

Results from rearing tests showed no significant differences in mean length or mean weight between fry from embryos incubated in watered versus dewatered conditions ($P > .0778$ length; $P > .2976$ weight). Mean total length ranged from 51.73 to 58.59 mm (watered), and from 49.46 to 58.24 mm (dewatered) (Table 13). Mean weight ranged from 0.993 to 1.145 gm (watered) and 1.006 to 1.116 gm (dewatered). No significant difference was found in length or final weight between fry with respect to sediment level, watered or dewatered incubation, and duration (2-4 weeks) $P > .0778$ length - $P > .3669$ weight). Average growth rates of watered and dewatered fry closely paralleled one another in both Hayden Creek and spring water, although rates were significantly higher in the latter ($P < .0001$) (Figure 25 and 26). Fry growth rates in Hayden Creek water ranged from 0.014 to 0.020 gm/day (watered) and 0.014 to 0.019 gm/day (dewatered) in spring water from 0.019 to 0.029 gm/day (watered) and 0.018 to 0.026 gm/day (dewatered) (Table 14) There was no significant difference in fry growth rates between those from watered versus dewatered chambers, when the Hayden Creek and spring water tests were combined ($P > .7395$).

TABLE 12. Mean Length, Total Weight, Yolk Weight And Body Weight Of Steelhead Alevins Resulting From Watered W Versus Dewatered D Egg Incubations Of From 1-4 Weeks Duration. Sampling Dates Do Not Necessarily Correspond To Hatching Dates. Hayden Creek Research Station. Spring 1979.

Sediment Level		Watered(W) or Dewatered(D) and Duration-wk	Date Sampled	N	Mean Total Length (mm) (S^2)	Range Length (mm)	Mean Total Dry Wt. (mg) (S^2)	Range Total Wt. (S^2)	Mean Yolk Wt (ms) (S^2)	Mean Body Wt (ms) (S^2)
30% < 4.6 > 0.84		W-1	7/11	15	17.53 (4.08)	11.5 - 20.0	29.4 (6.76)	25.2 - 34.3	25.4 (9.0)	4.10 (1.44)
20% < 0.84		D-1	7/5	15	14.27 (0.71)	12.5 - 15.5	33.8 (9.61)	27.7 - 37.2	32.0 (9.0)	1.80 (0.25)
		W-2	7/5	14	16.07 (0.53)	15.0 - 17.0	33.1 (4.84)	28.9 - 35.9	30.4 (5.29)	2.7 (0.49)
		D-2	6/27	13	13.42 (0.32)	12.5 - 14.5	33.7 (8.41)	29.3 - 37.5	32.2 (8.41)	1.5 (0.16)
		W-3	7/1	15	15.60 (0.58)	14.0 - 17.0	33.8 (11.56)	28.0 - 37.4	30.9 12.25)	2.8 (0.36)
		D-3	6/24	13	14.42 (0.20)	14.0 - 15.0	33.7 (8.41)	28.3 - 37.3	31.9 (7.29)	1.9 (0.16)
		W-4	6/30	15	16.53 (0.19)	16.0 - 17.5	34.1 (6.76)	29.1 - 37.1	30.3 (7.29)	3.8 (0.10)
		D-4	6/24	17	15.21 (1.10)	13.0 - 16.5	31.9 (5.76)	29.2 - 36.9	29.3 (6.25)	2.5 (0.49)
	$\overline{X}$	W			16.43					
		D			14.33					
20% < 4.6 > 0.84		W-1	7/11	11	15.41 (1.85)	13.0 - 17.5	29.0 (38.44)	11.5 - 36.1	24.8(50.41)	4.2 (3.61)
10% < 0.84		D-1	7/11	15	17.30 (1.72)	15.5 - 20.0	30.9 (7.84)	26.8 - 34.5	26.4(12.25)	4.6 (1.96)
		W-2	7/5	15	16.07 (0.21)	15.0 - 17.0	32.4 (7.29)	27.9 - 36.2	28.7 (6.76)	3.7 (0.49)
		D-2	7/11	15	20.03 (0.48)	19.0 - 21.0	29.2 (15.21)	24.2 - 37.2	20.8(14.44)	8.3 (1.96)
		W-3	7/1	15	15.93 (0.21)	15.0 - 16.5	35.1 (9.0)	29.5 - 39.0	32.3 (8.41)	2.8 (0.16)
		D-3	6/26	18	14.22 (6.35	12.0 - 16.0	32.2 (6.76)	27.8 - 37.0	30.3 (7.29)	1.9 (0.49)
		W-4	7/1	15	16.03 (0.27)	14.5 - 16.5	32.0 (9.0)	26.9 - 34.9	29.0 (9.0)	3.0 (0.81)
		D-4	6/26	15	15.53 (1.30)	14.0 - 18.5	33.9 (46.24)	27.9 - 56.6	28.9 (9.61)	3.3 (1.14)
	$\overline{X}$	W								
		D								
20% < 4.6 > 0.84		W-1	7/17	11	20.32 (1.06)	19.0 - 21.5	29.6 (9.61)	25.4 - 33.2	20.0 (14.4)	9.6 (4.41)
		D-1	7/15	16	16.84 (0.69)	14.5 - 18.0	33.7 (7.29)	29.2 - 39.4	30.2 (9.0)	3.4 (0.81)
		W-2	1/		1/	1/	1/	1/	1/	1/
		D-2	6/27	15	13.70 (0.64)	12.0 - 15.0	33.0 (14.44)	24.8 - 38.2	31.2 (14.44)	1.8 (0.9)
		W-3	7/5	15	16.47 (0.86)	15.0 - 18.0	31.2 (7.29)	28.5 - 35.9	28.2 (7.29)	3.1 (0.64)
		D-3	6/24	21	14.31 (0.66)	13.0 - 15.5	32.3 (28.09)	13.2 - 37.8	30.2 (23.09)	2.1 (0.25)
		W-4	7/5	15	16.93 (0.96)	14.5 - 18.0	31.8 (9.0)	26.0 - 35.3	27.8 (7.84)	4.0 (0.25)
		D-4	1/		1/	1/	1/	1/	1/	1/
	$\overline{X}$	W			17.91					
		D			14.95					
10% < 0.84		W-1	7/17	8	17.00 (13.62)	10.5 - 21.0	30.4 (16.00)	22.7 - 35.3	22.9 (27.04)	7.5 (4.00)
		D-1	7/11	15	16.77 (4.08)	13.5 - 19.0	29.2 (7.84)	23.3 - 31.8	25.1 (5.76)	4.1 (2.89)
		W-2	7/5	15	15.90 (2.53)	11.5 - 17.5	33.9 (7.84)	29.2 - 37.6	29.9 (7.29)	4.1 (1.0)
		D-2	7/3	15	16.13 (0.59)	15.0 - 17.0	31.3 (10.89)	27.9 - 37.2	28.1 (9.00)	3.2 (0.49)
		W-3	7/11	15	17.17 (9.18)	10.0 - 2.05	28.8 (31.36)	12.7 - 34.7	22.6 (26.01)	6.1 (4.0)
		D-3	6/26	9	15.67 (1.25)	14.0 - 17.0	30.6 (12.25)	27.0 - 36.1	26.8 (8.41)	3.7 (3.61)
		W-4	7/3	13	16.08 (0.49)	15.0 - 17.0	29.2 (5.76)	26.8 - 34.7	27.2 (6.76)	2.0 (0.49)
		D-4	6/24	16	15.34 (0.66)	14.0 - 17.0	34.7 (7.84)	29.5 - 38.8	31.6 (7.29)	3.1 (0.16)
	$\overline{X}$	W			16.54					
		D			15.98					

TABLE 13. Mean Length, Range Length, And Mean Weight Of Steelhead Fry Resulting From Watered W Versus Dewatered D Egg Incubations And Reared In Spring And Hayden Creek Water. Hayden Creek Research Station. Spring 1979.

Sediment Level	Rearing Water Source Spring (S) or Creek (C)	Watered (W) or Dewatered (D) or Duration-weeks	N	Mean Total Length (mm)	Variance S^2	Range Length (mm)	Mean Wet 1/ Weight gm
30% < 4.6 > 0.84	C	W-2	44	55.29	35.55	42.0 - 63.0	1.42
20% < 0.84		D-2	55	55.71	17.29	40.5 - 63.0	1.87
	C	W-3	66	52.14	37.92	35.0 - 62.5	1.54
		D-3	39	53.56	35.04	38.5 - 63.0	1.59
	C	W-4	44	52.14	40.61	35.0 - 61.5	1.48
		D-4	51	55.71	17.44	39.5 - 63.5	1.74
	$\overline{X}$	W		52.19			1.48
		D		54.99			1.73
20% < 4.6 > 0.84	C	W-2	74	52.06	23.47	40.0 - 62.0	1.51
10% < 0.84		D-2	74	52.51	34.38	36.0 - 67.0	1.59
	C	W-3	66	54.08	16.63	37.0 - 62.0	1.72
		D-3	79	49.46	46.00	34.0 - 63.0	1.33
	C	W-4	76	51.73	35.66	37.0 - 63.0	1.49
		D-4	79	54.09	19.70	41.0 - 61.5	1.64
	$\overline{X}$	W		52.62			1.57
		D		52.02			1.52
20% < 4.6 > 0.84	S	W-2	42	55.67	59.18	38.5 - 69.0	1.75
		D-2	48	55.61	27.56	38 - 66.5	1.90
	S	W-3	38	51.95	56.92	37.5 - 64.0	1.56
		D-3	35	57.03	49.29	41.5 - 67.0	2.07
	S	W-4	49	58.59	27.41	38.5 - 68.0	2.20
		D-4	42	58.24	45.06	40.5 - 71.5	2.13
	$\overline{X}$	W		55.40			1.84
		D		56.96			2.03
10% < 0.84	S	W-2	65	52.57	39.10	38.5 - 64.5	1.82
		D-2	65	53.75	33.56	39.0 - 66.0	1.72
	S	W-3	56	55.54	42.73	40.5 - 67.0	1.95
		D-3	45	55.19	38.83	38.5 - 65.5	1.81
	S	W-3	34	57.93	30.55	42.5 - 66.5	2.22
		D-4					2.05
	$\overline{X}$	W		55.35			2.00
		D		54.47			1.86

1/ From last sampling period.

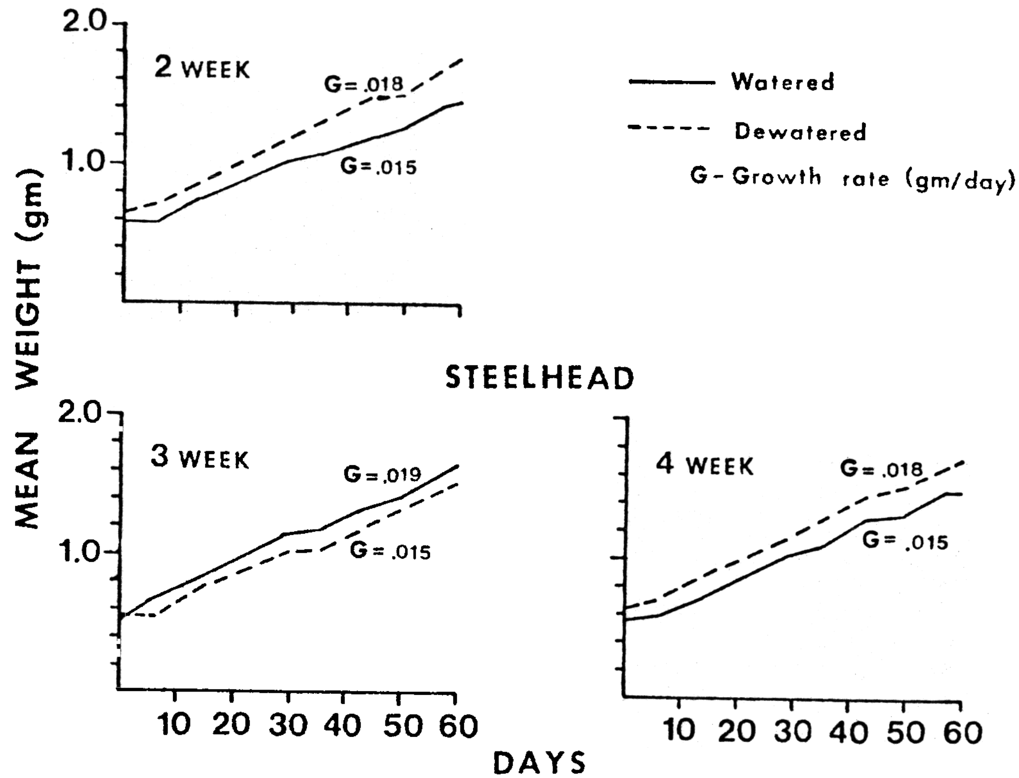


FIGURE 25. Comparison of Mean Growth (weight) of Steelhead Fry Resulting From Embryos Exposed To Conditions of Dewatering (2-4 Weeks) With Fry From Embryos Continuously Watered. Water Source During Rearing Tests = Hayden Creek. Hayden Creek Research Station. Fall 1979.

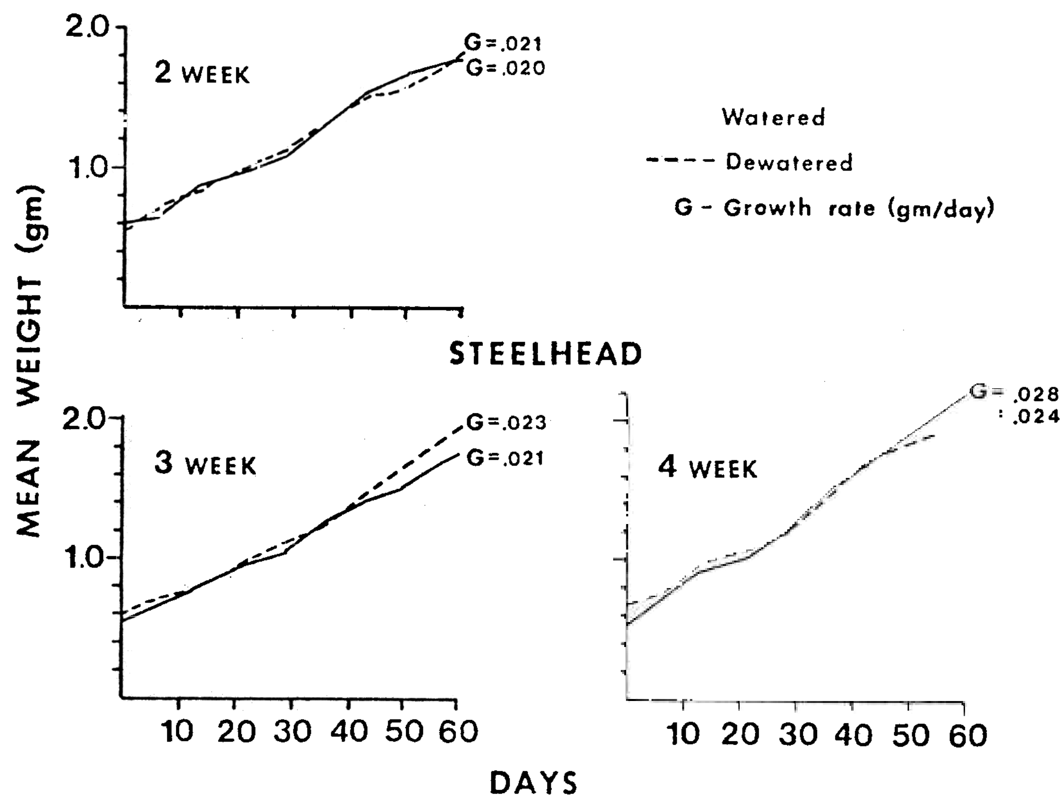


FIGURE 26. Comparison of Mean Growth (weight) of Steelhead Fry Resulting From Embryos Exposed To Conditions of Dewatering (2-4 Weeks) Wigh Fry From Embryos Continuously Watered. Water Source During Rearing Tests = Spring Water. Hayden Creek Research Station. Fall 1979.

TABLE 14. Average Weight (gm) Of Steelhead Fry At 10 Sampling Times During the 60 Day Fry Rearing Tests. Fry Resulted From Eggs Exposed From 1-4 Weeks Dewatering Within Four Levels Of Sediment. Hayden Creek Research Station. Spring 1978.

Sediment Level	Rearing Water Source Spring S or Creek C	Watered (W) or Dewatered (D) and Duration-Weeks	Aug 19	Aug 25	Sept 1	Sept 9	Sept 16	Sept 23	Sept 30	Oct 7	Oct 14	Oct 18 1/	Growth Rate gm/day
30% < 4.6 > 0.84		W-2	0.60	0.57	0.77	0.86	1.02	1.05	1.13	1.23	1.38	1.42	.014
20% < 0.84		D-2	0.71	0.75	0.89	1.12	1.28	1.39	1.57	1.63	1.81	1.87	.019
20% < 4.6 > 0.84		W-2	0.57	0.60	0.72	0.88	1.04	1.08	1.25	1.28	1.45	1.51	.016
10% < 0.84		D-2	0.55	0.67	0.78	0.91	1.07	1.21	1.34	1.40	1.54	1.59	.017
30% < 4.6 > 0.84		W-3	0.45	0.66	0.79	0.95	1.11	1.12	1.31	1.36	1.51	1.54	.018
20% < 0.84		D-3	0.65	0.61	0.81	0.94	1.10	1.17	1.32	1.40	1.53	1.59	.016
20% < 4.6 > 0.84		W-3	0.52	0.65	0.80	1.01	1.17	1.23	1.36	1.43	1.65	1.72	.020
10% < 0.84		D-3	0.49	0.51	0.66	0.72	0.88	0.93	1.07	1.15	1.33	1.33	.014
30% < 4.6 > 0.84		W-4	0.54	0.55	0.68	0.83	0.99	1.12	1.30	1.34	1.55	1.48	.016
20% < 0.84		D-4	0.65	0.71	0.90	1.05	1.21	1.34	1.55	1.60	1.67	1.74	.018
20% < 4.6 > 0.84		W-4	0.59	0.63	0.74	0.90	1.06	1.11	1.29	1.40	1.47	1.49	.015
10% < 0.84		D-4	0.59	0.69	0.80	0.97	1.13	1.21	1.33	1.40	1.60	1.64	.017
20% < 4.6 > 0.84	S	W-2	0.61	0.65	0.86	1.02	1.18	1.41	1.58	1.69	1.75	1.75	019
		D-2	0.52	0.69	0.87	1.05	1.21	1.41	1.57	1.63	1.93	1.90	023
10% < 0.84	S	W-2	0.57	0.61	0.86	0.93	1.09	1.28	1.56	1.60	1.73	1.82	021
		D-2	0.62	0.70	0.81	0.94	1.10	1.28	1.47	1.48	1.60	1.72	018
20% < 4.6 > 0.84		W-3	0.43	0.57	0.70	0.86	1.02	1.15	1.25	1.38	1.49	1.56	019
		D-3	0.51	0.66	0.75	0.96	1.12	1.23	1.50	1.67	1.91	2.07	026
10% 0.84	S	W-3	0.60	0.67	0.85	0.98	1.14	1.37	1.56	1.67	1.83	1.95	023
		D-3	0.65	0.64	0.80	0.93	1.09	1.19	1.41	1.62	1.81	1.81	019
20% < 4.6 > 0.84		W-4	0.57	0.78	0.91	1.14	1.30	1.62	1.87	2.09	2.20	2.20	027
		D-4	0.73	0.79	1.00	1.11	1.27	1.65	1.83	1.98	1.97	2.13	023
10% < 0.84		W-4	0.47	0.64	0.89	1.02	1.18	1.50	1.59	1.74	2.03	2.25	029
		D-4	0.60	0.70	0.91	1.03	1.19	1.44	1.73	1.69	1.90	2.05	024

1/ Fry preserved for length comparisons

Spring Chinook Test

Spring Chinook embryo survival to hatch ranged from 0 to 81.5% ($\overline{X}$ = 56.2%) in watered chambers and 67.5 to 85.5% ($\overline{X}$ = 75.8%) in dewatered chambers (Table 15, Figure 21) Survivals were much higher in dewatered than watered chambers containing the sediment mix 20% < 4.6 > 0.84 and 10% < 0.84 mm. Surviva was thus dependent on whether incubated in watered or dewatered conditions and sediment mix ($P \leq 0.025$). It is possible that extraneous sediment was transported via Hayden Creek during the steelhead tests when natural water runoff was occurring and was deposited within the watered chambers, thereby reducing intragravel flows. Overal hatching survival was independent of watered versus dewatered conditions and the number of weeks ($P > 0.10$).

During dewatering tests average water temperatures ranged from 6.0 C to 11.4 C, while air temperatures ranged from 5.0 C to 22.0 (Figure 27). Temperatures within the gravel of the dewatered chambers were generally higher than water temperatures, and ranged from 4.5 C to 12.8 C. Sheltered chambers had higher average intragravel temperatures than unsheltered chambers while in both cases temperatures were lower in the sediment mix containing 20% < 4.6 > 0.84 and 10% < 0.84 mm.

As in the steelhead tests, gravel moisture remained relatively constant throughout the 5 week dewatering period, even in the sheltered chambers, which prevented addition of moisture from weather events (Figure 24). The highest average moisture content ($\overline{X}$ = 7.77%) was found in the sediment mix 20% < 4.6 > 0.84 and 10% < 0.84 mm in the sheltered chambers, while the lowest ($\overline{X}$ = 5.07%) was also found in the sheltered chambers within the sediment mix 20% < 4.6 > 0.84 mm. Moisture levels within the unsheltered

TABLE 15. Comparison Of Spring Chinook Egg Survival And Ultimate Hatching Success Associated With 2-5 Weeks Of Dewatering (D), With Watered (W) Egg Survivals For Two Different Sediment Mixes. Tests Were Conducted In Unsheltered (U) And Sheltered (S) Chambers. Hayden Creek Research Station. Fall 1979.

Sediment Level	Chamber Numbers	Unsheltered(U)	Percent Egg Survival (Final Percent Hatch)									
			Week 2		Week 3		Week 4		Week 5		Mean $\overline{X}$	
20% < 4.6 > 0.84 and 10% < 0.84	1 + 5 - W 2 + 6 - D	U	94.5 (79.5)	97.5 (85)	90 (55.5)	94 (85.5)	61.5 (33.5)	86 (76.5)	50 (33.5)	90.5 (75)	74 (50.5)	92 (80.5)
	9 + 13 - W 10 + 14 - D	S	91.5 (74)	94.0 (76.5)	67.5 (37.5)	91.5 (69.5)	9 (2)	90.5 (75.5)	1.5 (0)	89 (73.5)	42.4 (28.4)	91.2 (73.7)
Mean $\overline{X}$			93.0 (76.5)	95.7 (80.7)	78.7 (46.5)	92.7 (77.5)	35.2 (17.7)	88.2 (76)	25.7 (16.7)	89.7 (74.2)	58.1 (39.4	91.6 (77.1)
20% < 4.6 > 0.84	4 + 8 - W 3 + 7 - D	U	90 (76)	94 (76)	91.5 (75)	91 (80)	92.5 (81.5	91.5 (82.5)	91 (66)	87 (71)	91.2 (74.6)	90.9 (77.4)
	12 + 16 - W 11 + 15 - D	S	92.5 (78.5	85.5 (71.5)	93 (60)	89 (75)	86.5 (68)	81.5 (67.5)	89 (78.5	89.5 (72)	90.2 (71.2)	86.4 (71.5)
Mean $\overline{X}$			91.2 (77.2)	89.7 (73.7			89.5 (74.7)	86.5 (75)	90 (72.2)	88.2 (71.5)	90.7 (72.9)	88.6 (74.4)
OVERALL Mean $\overline{X}$			92.13 (77)	92.7 (77.2)	85.5 (57)	91.4 (77.5)	62.4 (46.2)	87.4 (75.5)	57.9 (44.5)	89 (72.9)	74.5 (56.2)	90.1 75.8

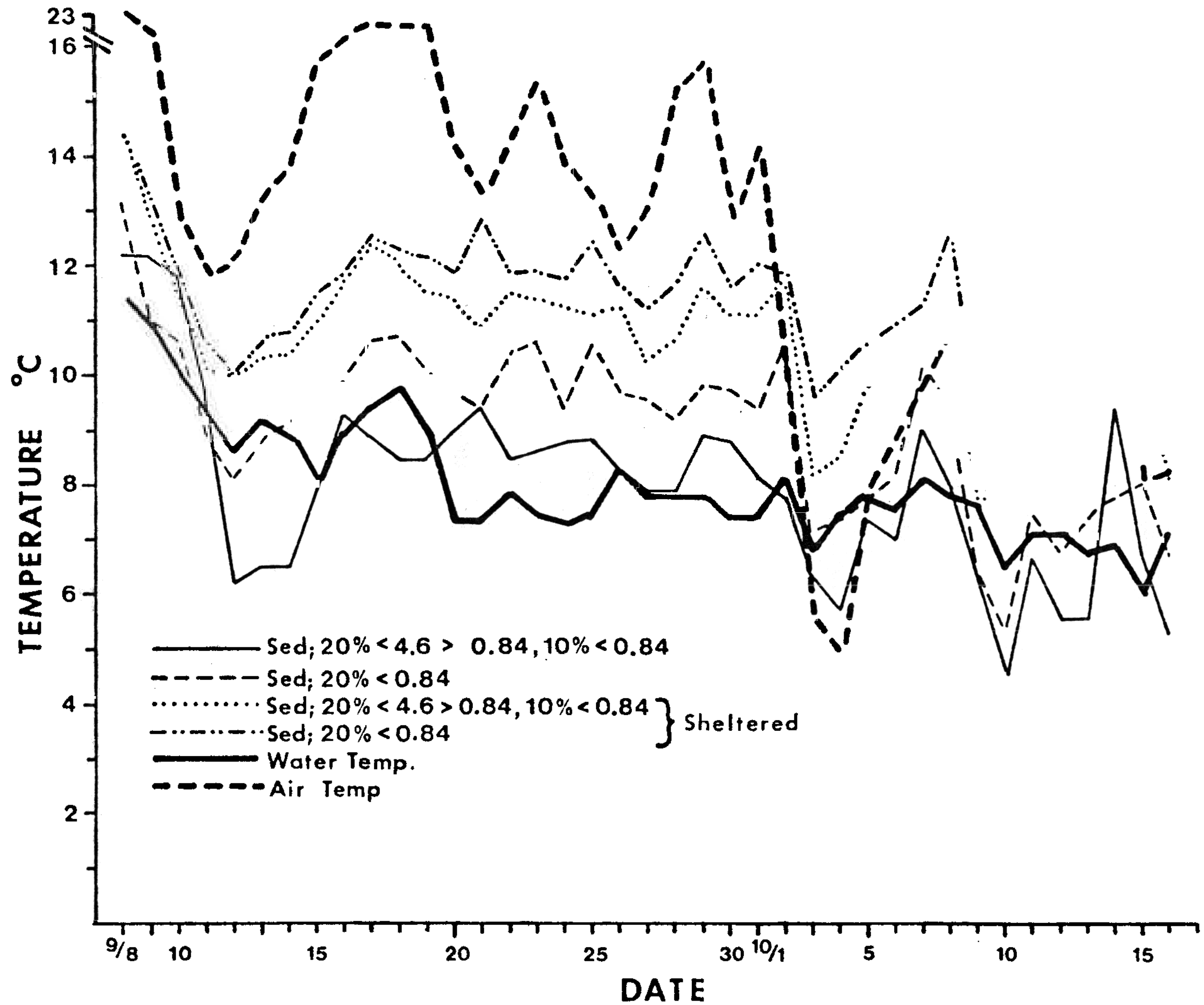


FIGURE 27. Mean Air and Water Temperatures, and Intragravel Temperatures From Unsheltered And Sheltered Chambers During Spring Chinook Embryo Dewatering Tests. Hayden Creek Research Station. Fall 1979.

counterparts of the mixes averaged 6.40 and 5.37% respectively. Rain occurred on only 1 day during the incubation period, which may explain the equality in moisture levels between sheltered and unsheltered chambers.

Alevins resulting from fertilized eggs incubated in dewatered chambers were significantly longer ($P \leq .0439$) than those from watered, although weights were not significantly heavier ($P > .3203$). Mean total lengths ranged from 22.0 to 24.6 (.86 to .96 inch) (watered) and from to 26.17 mm (.94 to 1.02 inch) (dewatered) (Table 16). Mean weights ranged from 295.0 to 327 mg (watered) and 290 to 331 mg (dewatered). The above differences are probably due to variation in intragravel temperatures. There was no significant difference in length or weight of alevins incubated in sheltered versus unsheltered chambers ($P > .7386$ length; $P >$ 1374 weight), within the two sediment types ($P > .2324$ length; $P >$ 0855 weight), or between the different incubation periods, 2-5 weeks 5314 length; $P > .0682$ weight).

Fry produced in watered and dewatered test conditions and reared for 57 days exhibited no significant differences in length ($P > .9125$), or weight ($P > .9393$). Average total length ranged from 49.60 to 57.55 mm (1.93 to 2.24 inch) (watered), and 51.73 to 56.18 mm (2.02 to 2.19 inch) (dewatered); mean weights from 1.25 to 1.85 gm (watered), and 1.36 to gm (dewatered) (Table 17). Growth rates during the 57 day rearing period ranged from .015 to .025 gm/day for watered, and from .017 to .24 gm/day, (dewatered) (Table 18). Mean growth rates of watered and dewatered fry closely coincided, and overall there was not significant difference ($P > .9128$) between them (Figure 28). Likewise, watered and dewatered

TABLE 16. Comparison Of Mean Length And Weight Of Chinook Alevins Resulting From Watered (W) Versus Dewatered (D) Egg Incubation From Sheltered And Unsheltered Chambers. Hayden Creek Research Station. Fall 1979.

Sediment Level	Sheltered (S) or Unsheltered (U)	Watered (W) or Dewatered (D) and Duration-weeks	N	Mean Total Length (mm)	Variance S^2	Range Length (mm)	Mean Wet Weight (ms)
20% < 4.6 > 0.84 10% < 0.84	U	W-2	15	24.40	0.94	22.5-25.5	311.0
		D-2	15	25.40	0.79	24.0-27.0	310.0
		W-3	15	22.07	1.25	19.0-23.5	307.0
		D-3	15	24.20	1.24	22.0-26.0	310.0
		W-4	15	23.27	1.53	21.5-25.5	305.0
		D-4	15	24.03	1.09	22.0-25.5	327.0
		W-5	15	22.30	1.85	20.0-24.0	301.0
		D-5	15	24.10	0.65	23.0-26.0	303.0
		W-2	15	23.93	2.03	20.0-26.5	302.0
		D-2	15	25.00	0.32	23.5-25.5	300.0
		W-3	14	24.00	0.62	22.5-25.0	306.0
		D-3	15	24.30	0.46	23.0-26.0	303.0
		W-4	4	22.00	0.17	21.5-22.5	325.0
		D-4	15	24.50	0.93	23.0-26.5	295.0
		W-5	1/	1/	1/	1/	--
		D-5	15	24.03	0.34	23.0-25.0	290.0
20% < 4.6 > 0.84	U	W-2	15	24.03	0.59	22.5-25.0	323.0
		D-2	15	25.23	0.78	23.5-26.5	319.0
		W-3	15	23.87	0.59	22.5-25.0	327.0
		D-3	15	24.80	0.81	23.0-26.0	322.0
		W-4	15	24.60	0.94	22.5-26.0	297.0
		D-4	15	25.00	0.82	24.0-26.5	322.0
		W-5	15	23.60	2.33	19.5-25.5	287.0
		D-5	15	24.73	1.32	22.0-26.0	328.0
		W-2		23.47	0.62	22.0-24.5	299.0
		D-2		24.10	0.54	23.0-26.0	320.0
		W-3		23.20	0.46	22.0-24.5	295.0
		D-3		25.93	0.32	25.0-26.5	319.0
		W-4		22.80	1.14	21.0-24.5	322.0
		D-4		26.17	0.99	25.0-27.5	331.0
		W-5		22.77	1.17	20.0-24.0	300.0
		D-5		24.57	0.89	230.25.5	293.0
Control Heath Stack			15	23.33	0.95	21.0-25.0	

TABLE   Comparison of Mean Length And Weight Of Chinook Fry Resulting From Watered W Versus Dewatered D Egg Incubations From Sheltered And Unsheltered Chambers. Hayden Creek Research Station. Fall 1979.

·ediment Level		Sheltered(S) or Unsheltered(D)	Watered (W) or Dewatered (D) and Duration-weeks	N	Mean Total Length (mm)	Variance S^2	Range Length (mm)	Mean Wet 1/ Weight gm
'0%	4.6 > 0.84		W-2	20	54.28	10.64	48.0 - 59.0	1.38
0%	0.84		D-2	20	54.78	6.80	48.5 - 60.0	1.47
			W-3	20	52.95	14.29	43.5 - 57.0	1.37
			D-3	20	52.70	24.72	43.0 - 63.0	1.46
			W-4	19	52.35	10.64	46.0 - 57.0	1.25
			D-4	20	53.35	11.87	45.0 - 58.5	1.36
			W-5	20	54.03	8.07	48.5 - 60.0	1.45
			D-5	20	55.65	12.92	47.5 - 60.0	1.57
			W-2	20	53.68	20.48	42.0 - 59.5	1.53
			D-2	20	53.60	11.09	45.0 - 58.5	1.41
			W-3	18	53.03	15.31	41.0 - 57.5	1.50
			D-3	20	52.65	29.84	39.5 - 61.0	1.46
			W-4					
			D-4	20	51.73	17.70	42.0 - 57.0	1.39
			W-5	2/	2/	2/	2/	
			D-5	20	54.60	9.81	48.0 - 58.5	48
20%	4.6 > 0.84	U	W-2	20	56.05	10.08	49.0 - 62.5	1.60
			D-2	20	53.53	8.20	46.0 - 57.0	1.45
			W-3	20	49.60	25.41	39.5 - 58.0	1.39
			D-3	20	55.13	16.39	47.0 - 61.5	1.75
			W-4	20	56.50	7.42	52.5 - 61.0	1.69
			D-4	20	54.30	11.04	46.5 - 60.0	1.59
			W-5	20	55.95	16.60	47.0 - 61.0	1.68
			D-5	20	56.18	8.45	50.5 - 61.0	1.81
			W-2	20	53.20	13.59	44.0 - 57.0	1.35
			D-2	20	54.90	14.33	41.0 - 60.5	1.72
			W-3	20	55.65	4.27	52.5 - 60.0	1.79
			D-3	20	53.78	12.35	47.5 - 59.5	1.39
			W-4	20	54.78	12.09	47.0 - 61.0	1.47
			D-4	20	56.38	10.09	51.5 - 64.5	1.75
			W-5	20	57.55	6.18	53.5 - 62.0	1.85
			D-5	20	52.0	5.50	46.0 - 56.0	1.42

1/ From last sampling period

2/ 100% eggs mortality

TABLE 18. Average Weight (gm) Of Chinook Fry At Eight Sampling Times During 56 Day Fry Rearing Tests. Fry Resulted From Eggs Exposed From 2-5 Weeks In Sites Dewatering Within Two Levels Of Sediment. Hayden Creek Research Station. Fall 1978.

Sediment Level	Sheltered(S) or Unsheltered(U)	Watered (W) or Dewatered (D) and Duration-weeks	Ave. weight (gm) during dates sampled: Jan 15	Jan 22	Jan 29	Feb 9	Feb 15	Feb 23	Mar 3	Mar 12	Growth rate gm/day
20% < 4.6 > 0.84	U	W-2	0.415	0.56	0.56	0.933	1.00	1.200	1.23	1.38	.017
		D-2	0.415	0.66	0.66	0.900	0.95	1.217	1.37	1.47	.019
10% < 0.84	S	W-2	0.415	0.76	0.76	0.833	1.00	1.183	1.32	1.53	.020
		D-2	0.415	0.64	0.64	1.085	1.034	1.237	1.29	1.41	.017
20% < 4.6 > 0.84			0.415	0.57	0.57	1.050	1.067	1.267	1.43	1.60	
			0.415	0.63	0.63	0.85	1.050	1.150	1.32	1.45	
	S		0.415	0.55	0.55	1.017	1.017	1.150	1.32	1.35	
			0.415	0.66	0.66	1.017	1.133	1.283	1.55	1.72	
20% < 4.6 0.84		W-3	0.415	0.78	0.78	0.833	1.217	1.100	1.330	1.37	
		D-3	0.415	0.55	0.55	0.831	0.881	1.119	1.140	1.46	
10% 0.84		W-3	0.415	0.60	0.60	0.847	1.203	1.220	1.240	1.50	
		D-3	0.415	0.63	0.63	0.847	0.947	1.153	1.360	1.46	
20% < 4.6 > 0.84	U		0.415	0.60	0.60	0.917	1.017	1.067	1.220	1.39	
			0.415	0.64	0.64	0.883	1.100	1.267	1.540	1.75	
			0.415	0.69	0.69	0.897	1.241	1.397	1.59	1.79	
			0.415	0.60	0.60	0.967	1.083	1.217	1.32	1.39	
20% 4.6 > 0.84	U		0.415	0.51	0.51	1.00	0.867	1.133	1.23	1.25	015
			0.415	0.46	0.46	0.797	1.035	1.136	1.27	1.36	017
10% < 0.84			0.415	0.67	0.67	1.00	1.350	1.40	1.40	1.50	019
			0.415	0.63	0.63	0.814	1.119	1.186	1.29	1.39	017
20% < 4.6 > 0.84	U	W-4	0.415	0.66	0.66	0.967	1.133	1.317	1.56	1.69	022
		D-4	0.415	0.69	0.69	1.00	1.167	1.217	1.37	1.59	021
		W-4	0.415	0.68	0.68	0.933	1.034	1.220	1.46	1.47	019
		D-4	0.415	0.64	0.64	0.933	1.183	1.339	1.61	1.75	023
20% < 4.6 > 0.84		W-5	0.415	0.64	0.64	0.800	1.067	1.083	1.23	1.45	018
		D-5	0.415	0.72	0.72	0.917	1.150	1.30	1.37	1.57	020
0% < 0.84		W-5	1/	1/	1/	1/	1/	1/	1/	1/	1/
		D-5	0.415	0.57	0.57	0.733	1.053	1.033	1.23	1.48	019
0% < 4.6 > 0.84		W-5	0.415	0.62	0.62	0.915	1.119	1.254	1.51	1.68	022
		D-5	0.415	0.64	0.64	0.983	1.00	1.288	1.59	1.81	024
		W-5	0.415	0.67	0.67	0.983	1.183	1.317	1.72	1.85	025
		D-5	0.415	0.62	0.62	0.833	0.983	1.067	1.30	1.42	018

1/ 100% egg mortality

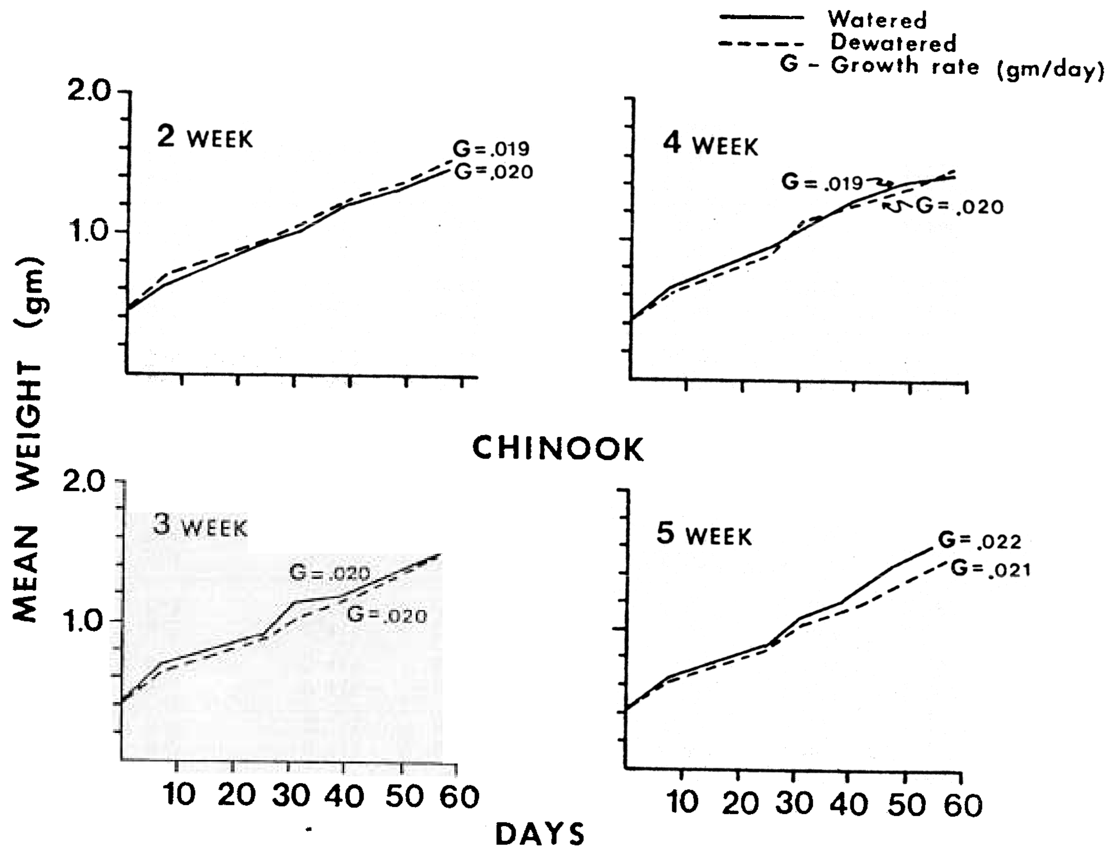


FIGURE 28. Comparison of Mean Growth (weight) of Chinook Fry Resulting From Embryos Exposed to Conditions of Dewatering (2-5 Weeks), With Fry From Eggs Continuously Watered. Water Source During Rearing Tests = Spring Water, Hayden Creek Research Station, 1979.

growth rates were not significantly different among the 2-5 week test durations ($P > .8083$).

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DISCUSSION

Streamflow Fluctuations

Embryo Survival

No definitive relationship was found betwen embryo survival and the incidence of flow fluctuations and periodic redd exposure in either the field or laboratory tests. However, in the field tests, the highest embryo survival did occur in the area where redds were cumulatively dewatered the least, and there were significant inverse relationships between both cumulative and maximum duration of dewatering and embryo survival. These correlations, however, were somewhat tenuous ($r = -.2503$) with embryo survivals in some cases extremely low (less than 25%) even in redds which were never dewatered. Spring chinook embryo survival from the laboratory tests averaged 74% in the control (constant flow) and 69.6% in the test (flows fluctuated).

Meekin (1967) in a study below Chief Joseph Dam on the Columbia River reported embryo survivals of 92% from unexposed natural chinook redds and 88% from redds periodically dewatered. His conclusion was that damage to buried embryos was neglible. In contrast, Thompson (1974) reported significant mortality of eyed steelhead embryos subjected to "brief" periods of dewatering associated with flow fluctuations below Hells Canyon Dam. Thompson provided no specific survival information and conceded that mortality data was substantially inconclusive.

Handling Mortality

Handling was one source of mortality which contributed to reduced embryo survival in field tests. Fertilized eggs used in tests were transported in water from the Bonneville Hatchery and planting was not complete until 27 hours after the egg take.

Leitritz (1963) reported that fertilized green eggs can be shipped for a period of up to 48 hours after spawning, provided severe jolting and temperature elevation can be prevented. Although temperature was no problem in our study, embryos were subjected to sporadic agitation during transportation. Although we were not able to specifically evaluate handling mortality in field tests, visual mortality estimates ranged from 0 to 25%. In a similar study investigating peaking impacts on fall chinook incubation below Priest Rapids Dam on the Columbia Rivers fertilized green egg mortality was as high as 90 to 95% at the time of planting, just 5 hours after the embryos were spawned (Don Chapman and Tom Welch, personal communication). Welch felt that eggs from the Priest Rapids stock of fall chinook were extremely sensitive to handling. In our study, approximately 2000 extra embryos remained in the coolers until the day following the planting operation. We estimated 10 to 15% mortality after 50 hours plus since spawning. Thus, it appears that embryo mortality found in Hells Canyon was not totally a result of handling.

Sediment

The amount of fine sediment within artificial redds in Hells Canyon could also have affected embryo survival regardless or whether embryos were watered or dewatered. Many studies have cited the deleterious effects of sediment on embryo incubation and fry emergence. If the study sites are representative of those selected by fall chinook in the Snake River, and there is evidence they are, embryo survival and emergence from natural redds may be low. Overall, survival to hatch in the control redds which were never dewatered, averaged 33.9% although survival to emergence would have been poor. Within these artificial redds the entire gravel filled W-V box was saturated with fine sediment. According to Beschta and Jackson (1978), sediment deposition and intrusion into the substrate involves transport and deposition of fines into the surface voids, and the settling of particles into deeper gravel voids. The depth to which the material settles is dependent on flow characteristics with higher velocities and greater bed shear allowing deeper settling of material. Beschta and Jackson reported that the flushing of fines can only occur during periods of high flow when the channel bed is disturbed causing bedload transport. In Hells Canyon, the rapid fluctuation in flows appear to be resulting in bedload transport during periods of high flow, followed by sediment deposition and intrusion during periods of low flow. With this type of regime, the relatively clean gravels resulting from redd building activity of the female salmon, will be rapidly filled with fine materials. In contrast, the historical hydrograph associated with the Snake River followed a general pattern of decreasing flows during the fall and winter months. Thus, there would be little transport of sediment into spawning area gravel during fall chinook embryo incubation and fry emergence.

Rate of Dewatering

Sediment levels influenced test embryo survival in laboratory channel tests. However, survival may have been more related to how quickly the redds become dewatered rather than the specific level of sediment, although sediment levels are determinants of dewatering rates.

Rate of water movement through soils is determined by permeability which in turn depends on the sizes quantity and texture of materials comprising the substrate. Substrates composed of large quantities of fine sediment have lower permeabilities than those with less amount or larger sediment and therefore, would take a longer time to become dewatered.

Embryo survival in Hells Canyon may also have been influenced by rates of dewatering. Embryos within gravels containing high levels of sediment may, upon flow cessation be subjected to essentially stagnant water until downward percolation occurs and the eggs become completely dewatered. Because intragravel water velocity is important in transporting oxygen to and metabolic waste material from incubating eggs, its reduction or cessation may be deleterious to embryo survival. O'brien et al. (1978) reported that natural convection processes may act as an emergency oxygen transport mechanism for embryos during periods of low velocities. However, if oxygen is not replenished to the surrounding water, the convective cycles would eventually deplete the oxygen content below that necessary for survival. Gradual reductions in flow over redds may result in concomitant reductions in intragravel velocity which may eventually reach critical levels. Maintaining a few centimeters of non-moving water over redds to keep embryos moist may be more baneful than complete dewatering. If embryos are subjected to periodic dewaterings, it may be less detrimental if they attain the exposed state as quickly as possible thereby avoiding long periods of containment within non-moving water.

Freezing

Although intragravel temperatures in the Snake River during periods of redd dewatering were reduced on several occassions below 0 C, we found no evidence (i.e. water filled vials were unbroken) suggesting the embryos were subjected to freezing conditions. However, the water. filled vials may simply not have had sufficient time to freeze between flow fluctuations.

Incidence of intragravel freezing is largely controlled by ambient air temperatures which may markedly differ from year to year. Certainly exposure of redds during periods of extreme cold predisposes them to freezing conditions. McNeil (1966) reported embryo and fry mortalities of up to 65% resulting from intragravel freezing. He concluded that the highest mortalities were generally associated with streams having the lowest discharge. With respect to embryos which are periodically dewatered, freezing should be considered the primary mortality factor.

Thermal Shock

Although not an apparent problem in field or laboratory peaking tests, thermal shock, due to sudden increases or decreases in temperature, could occur to embryos in the dewatered state when flow is restored. Bell (1973) stated that especially during the "tender" (pre-eyed) period of incubation, excessive mortality may result from a sudden raising or lowering of temperatures. To circumvent this problem in hatcheries, embryos are tempered to within 2.8 C of the water temperature into which they are being transferred.

Other Imposed Conditions

Other flow fluctuation related conditions which may reduce survival include air entrapment and gravel settling.

Air entrapment may occur when gravel becomes dewatered below sheltered voids which then trap air upon flow restoration. Johnson (1980) found a dramatic reduction in permeability of gravel containing entrapped air. This could impair oxygen transfer rates of incubating embryos resulting in high mortalities. Although the trapped air will eventually reenter solution, if the dewaterings are frequent, it could become a chronic condition.

Gravel settling occurs when the substrate becomes dewatered thereby coming under the full influence of gravitational forces. Dewatered embryos may be subjected to movement and external pressure resulting from the settling of the overlying substrate (Fred Watts, personal communication, Civil Engineering Deparmtent, University of Idaho). Potentially this could be deleterious to embryos, particularly during the tender stage of development. During this period, extending from approximately 48 hours after spawning to when the embryos develop visible eye spots, the embryos are extremely sensitive to movement, which may result in rupture of the yolk membrane and death. Both of the above conditions warrant further investigation.

Fry Survival

Although incubating embryos appear to be largely unaffected by periods of dewatering, newlyhatched alevins are far less tolerant, as evidenced by previous tests (Reiser and White, 1980 in press) in which chinook embryos were incubated in moist cotton cloth until hatching commenced. Embryos were monitored every 24 hours and newly hatched alevins removed to vertical flow incubators. As many as 38% of the hatched alevins within a 24 hour period died before being transferred. Because hatching occurred throughout the 24 hours, the dead alevins resulted from embryos which hatched first and were therefore exposed to dewatered conditions the longest. Assuming an even hatch throughout any 24 hour period we estimated alevin dewatering tolerance to be less than 10 hours. Further studies are needed to specifically evaluate the effects of flow fluctuation on alevin and fry survival.

EMBRYO DEWATERING TOLERANCE

Streamflow reductions and/or cessation may completely dewater salmonid redds. Results of our laboratory tests indicate that dewatered fertilized eggs are extremely tolerant to long periods of dewatering (provided they are kept moist) with no significant effects on survival to hatching, growth rates, or fry quality. Hobbs(1937), in a study of the Selwyn River in New Zealand, Jocated several brown trout redds which had been dewatered for approximately 5 weeks. Survival assessment within a typical redd indicated 83% of the ova were alive. Similar findings of healthy brown trout ova within exposed redds of the Selwyn River were reported by Hardy (1962). Hawke (1978) found viable chinook embryos within stranded redds in the Mathias River, South Island, New Zealand. He estimated that water had not flowed over the redds for approximately 3 weeks. In our tests we found that salmonid embryos were capable of successfully completing their entire embryogenesis (including hatching) in a dewatered state, provided the surrounding gravel remained moist.

Moisture Content in Dewatered Redds-

Moisture retention is to a large degree dependent upon the amount and texture of sediment present in the redd, with finer textured materials able to retain a greater percentage of moisture. Thus, moisture content was highest in the sediment mix 30% $<4.6 > 0.84$ and 10% < 0.84 mm, However, moisture retention alone can not explain the relatively constant amounts of moisture following 5 week dewatering tests. Discounting precipitation as a source of moisture replenishment, two mechanisms acting within the gravel may sustain high moisture levels. The first, capillarity, entails the upward movement of water from the water table through the interstices of the sediment (Buckman and Brady, 1972). This process is impeded by trapped air and large pores and for this reason probably operated only in gravel mixes containing an abundance of fines. The second mechanism, water vapor transfer, is more likely responsible for the maintenance of moisture in coarse textured gravels as would be found in salmonid redds (Glenn Lewis Personal Communication, Soils Department, University of Idaho). This process results from the presence of a vapor-pressure gradient between two adjoining areas. If one area has a high moisture content (e.g. close proximity to groundwater flow) and high vapor pressure, and an adjacent area is relatively dry with a low vapor pressure, a diffusion of moisture into the dry area will tend to occur. This process may be enhanced if the temperature of the dry substrate mass is lowered resulting in a decrease in vapor pressure and diffusion of water vapor into the area. Such reductions in temperature within dewatered redds would probably occur near the surface,' where the influence of external nighttime ambient temperatures would be maximized. For this reason, vapor transfer probably operates most efficiently during the evening. During the daytime, the upper layers of gravel will become warmer than the deeper, moist layers resulting in minimum vapor transfer. Provided a layer of groundwater remains in close proximity to dewatered eggs, the mechanisms of vapor transfer and to a lesser degree capillarity, should replenish moisture loss from the surrounding gravel-sediment mix, even during extended periods of dewatering. Specific distance limits from embryos to groundwater levels within which these mechanisms will continue to operate are unknown and warrant further investigation. In our laboratory tests water levels were approximately 10 cm below dewatered embryos.

Our tests suggest that gravel moisture levels of approximately 4% or more are sufficient to allow salmonid embryos to withstand relatively long periods of redd dewatering, provided temperatures remain within incubation tolerances.

Sediment

In addition to retarding moisture loss from the surrounding embryos, sediment also provides an insulating layer to buffer temperature fluctuations associated with the external environment. This is especially important during periods of extreme cold. In addition, the percentage level of sediment is important as it must allow atmospheric oxygen infiltration to the eggs Oxygen is supplied to eggs in dewatered redds via the continuous diffusion of atmospheric air into the intragravel spaces, the dissolving of oxygen into the thin layer of water surrounding the embryo and the diffusion of oxygen through the egg capsule to the developing embryo.

Embryo Development

The most obvious effect of long term periods of dewatering on steelhead and spring chinook embryos was accelerated development with hatching dates in some cases 14 days earlier than those incubated in water. Regardless of being incubated in watered or dewatered conditions or the duration of such incubations, fry which had been reared for 57-60 days exhibited no significant difference in length or weight. In situations where intragravel temperatures may be less than water temperatures, we would expect delayed development and hatching times.

SUMMARY

1) In Hells Canyon no definitive relationship was found between embryo survival and the incidence of flow fluctuations and periodic redd exposure. However, the highest survivals occurred in areas dewatered the least.

2) In laboratory tests, no significant differences in survival were found between embryos periodically dewatered (11-12 hours/day) and those continuously watered.

3) Rate of dewatering may influence embryo survival. If embryos must be subjected to periodic dewaterings, it may be less injurious if they attain the exposed state as quickly as possible thereby avoiding long periods of containment with non-moving water.

4) There was extensive sediment intrusion into the artificial fall chinook redds within Hells Canyon. Such accumulations may be caused by the rapid fluctuations in flows resulting in alternate cycles of bedload transport, sediment deposition and sediment intrusion.

5) No evidence of intragravel freezing was found during periods of dewatering in either the field or laboratory study. However, water filled vials may not have had sufficient time to freeze between flow fluctuations.

6) Dewatered redd intragravel temperatures in Hells Canyon were generally colder than ambient water temperature. Thus, embryo development may be delayed in redds periodically dewatered.

7) Dewatered intragravel temperatures in laboratory tests were generally higher than water temperatures and resulted in significantly larger and heavier alevins. Such differences were transitory with no fry quality differences upon completion of rearing tests.

8) Thermal shock, air entrapment and gravel settling may occur as a result of flow fluctuation and could adversely affect egg survival.

9) Steelhead trout and chinook salmon eggs were tolerant to 1-5 weeks of dewatering with no significant effects on survival to hatching (provided embryos remained moist), alevin quality, growth rates or latent fry quality.

10) Alevin dewatering tolerance limits are estimated to be less than 10 hours.

11) Gravel moisture within dewatered redds remained relatively constant throughout the 1-4 (steelhead) and 1-5 (chinook) week dewatering period. Water vapor transfer is the probable mechanism responsible for replenishing lost moisture within dewatered redds.

12) The most pronounced effect of long term dewatering on steelhead and spring chinook embryos was accelerated development with hatching modes as many as 14 days earlier than those incubated in water.

13) Regardless of incubation condition tested (watered or dewatered) or duration, fry reared 57-60 days exhibited no significant differences in length or weight.

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